Title of Investigation:

Oriented Nanocomposite Extrusion (ONE)

Principal Investigator:

Dan Powell (Code 542)

Other In-house Members of the Team:

Sateesh Bajikar (Code 560), Steve Wood (Code 544), Greg Bowers (Code 547), Willie Barber (Code 544), Carl Stahle (Code 553), and Mark Foor (Code 540), and Mike Viens (Code 541)

Other External Collaborators:

Hugh Bruck and Arun Kota (University of Maryland-College Park); and Mino Freund (Air Force Research Lab)

Initiation Year:

2003

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

$75,000

FY 2004 Funding Authorized:

$35,000

Actual or Expected Expenditure of FY 2004 Funding:

$35,000; In-house: $12,000; Grants: $23,000 to the University of Maryland-College Park

Status of Investigation at End of FY 2004:

To be continued in FY 2005, with funds remaining from FY 2004 and earlier years

Expected Completion Date:

November 15, 2004

Purpose of Investigation:

Oriented carbon nanotube (CNT) composites should be able to achieve orientable, mechanical strengths that are 4 to 50 times greater than substrate material. They also should be able to reduce vehicle weight and costs. Further, use of CNT composites would give projects longer lifecycles, thermal delocalization, and selectable electromagnetic shielding/polarization. By quantifying composite properties and fabrication processes for oriented CNT composites of various substrates, a knowledge base will be created for future work on scaling-up fabrication and tailoring/enhancing composite properties for mission-specific applications. A long-term goal of this work is to transfer technology to industry by way of patent licensing through the Goddard Commercialization Office.

Accomplishments to Date:

The initial investigation was broken into three distinct, but complimentary tasks: 1) rheometric measurements of Multiwalled Carbon Nanotube (MWNT)-loaded polymers at temperatures near their processing temperature; 2) computational fluid dynamics (CFD) to size the initial microchannel cross-section and guide design of the microchannel extrusion die; and 3) design and fabrication of the extrusion die and die-housing.

Rheometric measurement of 3-5 MWNT-loaded polymer samples was conducted, resulting in the identification of a variety of polymer substrates, which may be appropriately employed in this investigation. Based upon rheometric investigation of MWNT-loaded polymers within the 0-3%, by weight, range, microchannel cross-sections and aspect ratios also were significantly altered from those initially proposed. Identification of both a novel shear-thickening phenomena and accelerating exponential viscosity curve resulted from rheometry study of polymers loaded with MWNTs in the 1-3wt% range.

Extensive Navier-Stokes CFD was conducted to solidify parity of actual MWNT-loaded polymer viscosity while qualifying conceptual die designs. Knudsen number analyses were conducted for each candidate polymer to verify the appropriateness of the no-slip assumption in the Navier-Stokes development. A three-dimensional Lattice-Boltzmann one-phase MATLab code was developed and successfully qualified for channel cross-sections and melt viscosities of indicated by the Navier-Stokes CFD discussed above as a precursor to a two-phase code developed to study in situ alignment of MWNTs flowing though channels of varying dimensions. This investigation's substrate viscosity tolerance, MWNT-loading range, and extrusion die metrics were successfully bounded through closed-form Navier-Stokes analysis, and verified through Navier-Stokes and Lattice-Boltzmann FEA simulation.

Design for fabrication of a flexible and scalable microchannel extrusion has been completed and accepted by Code 553 for fabrication. Design of the microchannel die housing and twin-screw extruder (TSE) interface is nearly completed but has been delayed by priority flight-failure investigation work, which was not anticipated.

Fabrication of the microchannel extrusion die has been delayed until June 1st, 2004 due to personnel shortages and lack of facility availability within Code 553.0. Although significant progress has been made, as previously mentioned, design of the die housing also has been delayed due to a priority flight-failure investigation within Code 543.

Planned Future Work:

Recent progress on the fabrication and characterization of oriented nanocomposites via a scalable twin-screw extrusion process has made practical discussions of scale-up and spin-out of fabrication hardware design and process technologies with industry partners, including Spartech Corp., Clayton, Missouri, to facilitate development of macro-scale (meter-wide) production of commercial-off-the-shelf (COTS) composites to support a variety of missions agency-wide. The performance and capability improvements of oriented CNT composites over current material capabilities are dramatic. CNTs have an axial modulus >1TPa, allowing their composites to be potentially stronger than steel in tension, yet flexible with near infinite life. CNTs axially conduct heat at >3,000W/mK and electricity six orders-of-magnitude better than copper, allowing their composites to de-localize any concentrated heat source and behave as ballistic electrical conductors.

Current mission-infusion opportunities for oriented CNT composites include multifunctional and in-flight repairable skins and structure for the Crew Exploration Vehicle, inflatable habitats for the moon and Mars sunshields for a variety of missions including the James Webb Space Telescope and next-generation extravehicular activty suits. A CNT film could rapidly redistribute the heat load, resist puncture, and arrest propagation of any tear as it develops. It also has potential to be further functionalized as a layerable radiation-shielding material for interplanetary proton events and emergency shelters for the Moon and Mars.

The major challenge to scale-up and spin-out of such oriented nanocomposite hardware design and process technology is demonstration of a new design paradigm to progress from the 3-inch wide samples we've produced using an etched silicon-die and the ~1 foot wide demonstration proof that Spartech and others would require to iterate to meter-scale production.

This proposal addresses the challenge of scale-up through the design for fabrication of parallel, interdigitated plates about 1-foot in width that may be defensibly iterated for meter-scale fabrication of composite laminate layers of continuous length. David G. Pocost, executive vice president for technology development at Spartech Corp. has agreed to work closely with our design and development team to insure that our ~1 foot wide microchannel die can be directly leveraged for integration into its new $50 million twin-screw extrusion R&D facility in Richmond, Indiana. Project objectives include:

- Develop a new design regime for ~1-foot wide microchannel dies.
- Characterize best practice manufacturing techniques and assess interface/integration considerations for spin-out of ~1-foot microchannel die composite production.
- Collaborate with Spartech Corp. and others to insure defensible meter-scale scale-up of selected design and manufacturing methodology and to establish qualified COTS partnership development to enable future NASA missions.

Summary:

Among the project's innovative features are: 1) identification of a novel two-phase shear-thickening behavior; 2) development of a scaleable nanocomposite production process; and 3) verification of multifunctional composite material properties against literature.

The potential payoff to the Goddard Space Flight Center includes: 1) standardization of advanced composite acquisition through licensing of these processes to industry; 2) cost reduction because we can replace graphite epoxy with the robust, lightweight, multifunctional composites we've developed; 3) support for more capable missions because high-performance, multifunctional, nanostructured composites are available; and 4) system mass reduction through direct replacement of graphite epoxy and other structural materials with high-strength nanostructured composites.

The effort's criteria for success include: 1) the development of a macroscale fabrication process for multifunctional nanostructured composites; 2) production of macroscale nanostructured composites; 3) characterization and verification of multifunctional material property enhancements against state-of-the-art as presented in the technical literature; and 4) development of a technology transfer for scale-up and COTS development with an industry partner.

The technical risk factors that might prevent us from succeeding include: 1) production equipment failure; 2) melt-formulation viscosity limitation on process control; 3) production equipment procurement and fabrication limitations; 4) original equipment manufacture production delays and failures; and 2) composite characterization methodology and instrument availability challenges.