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Lightweight Damage Tolerant, High-Temperature Radiators for Nuclear Power and Propulsion

Project Manager(s)/Lead(s)

Paul D. Craven Ph.D./EM50
(256) 544–7649

Michael P. SanSoucie/EM50
(256) 544–5269

Sponsoring Program(s)

Space Technology Mission Directorate
Center Innovation Fund

Project Description

NASA is increasingly emphasizing exploration to bodies beyond near-Earth orbit. New propulsion systems and new spacecraft are being built for these missions. As the target bodies get further out from Earth, high energy density systems, e.g., nuclear fusion, for propulsion and power will be advantageous. The mass and size of these systems, including supporting systems such as the heat exchange system, including thermal radiators, will need to be as small as possible. Conventional heat exchange systems are a significant portion of the total thermal management mass and size.

Nuclear electric propulsion (NEP) is a promising option for high-speed, in-space travel due to the high energy density of nuclear fission power sources and efficient electric thrusters. Heat from the reactor is converted to power for use in propulsion or for system power. The heat not used in the power conversion is then radiated to space as shown in figure 1.

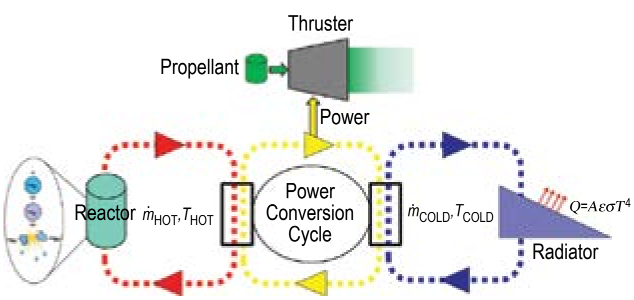

Figure 1: NEP system.

Advanced power conversion technologies will require high operating temperatures and would benefit from lightweight radiator materials. Radiator performance dictates power output for nuclear electric propulsion systems. Pitch-based carbon fiber materials have the potential to offer significant improvements in operating temperature, thermal conductivity, and mass. These properties combine to allow significant decreases in the total mass of the radiators and significant increases in the operating temperature of the fins.

A Center-funded project at NASA Marshall Space Flight Center has shown that high thermal conductivity, woven carbon fiber fins with no matrix material, can be used to dissipate waste heat from NEP systems and because of high specific power (kW/kg), will require less mass and possibly less total area than standard metal and composite radiator fins for radiating the same amount of heat.

This project uses an innovative approach to reduce the mass and size required for the thermal radiators to the point that in-space NEP and power is enabled. High thermal conductivity carbon fibers are lightweight, damage tolerant, and can be heated to high temperature.

Areal densities in the NASA set target range of 2 to 4 kg/m^2 (for enabling NEP) are achieved and with specific powers (kW/kg) a factor of about 7 greater than conventional metal fins and about 1.5 greater than carbon composite fins. Figure 2 shows one fin under test. All tests were done under vacuum conditions.

Anticipated Benefits

Woven bare carbon fibers used as the radiating surface or fin is an innovative approach. Using the bare carbon fiber with no, or little, matrix material avoids the additional mass of the matrix material and a reduced thermal conductivity also associated with the matrix material.

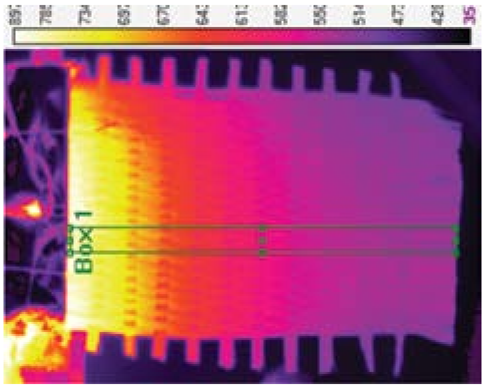

Figure 2: Woven bare carbon fibers under test in vacuum chamber.

Potential Applications

Woven bare carbon fins are applicable to all future missions using nuclear electric power and propulsion and to some solar system planetary surface missions for which solar power is not a viable option.

Notable Accomplishments

The following accomplishments were achieved: (1) Weaving the high thermal conductivity carbon fibers into a mat. This was done, apparently for the first time with K13D2U, by Textile Engineering and Manufacturing, a commercial company. The fact that fins using the K13D2U can be woven commercially means the fins can be mass produced; and (2) Attaching the fins to a heat pipe. Figure 3 shows the cross section of an experimental sample attachment using TiCuSil, a commercially available active braze material.

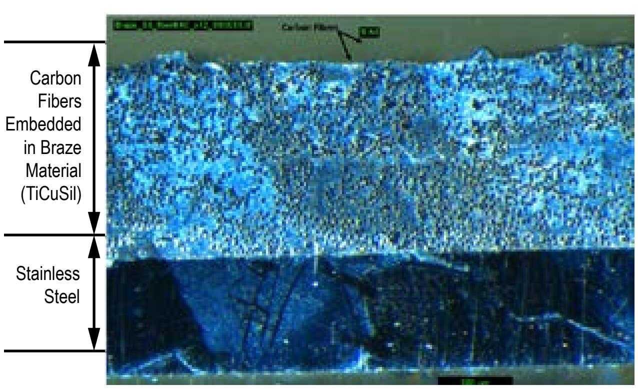

Figure 3: Cross section of braze sample processed in the vacuum isothermal oven.

Publications/Presentations

SanSoucie, M.P.; Rogers, J.R.; Craven, P.D.; and Hyers, R.W.: "Experimental Studies of Carbon Nanotube Materials for Space Radiators," Poster Presentation, National Space & Missile Materials Symposium (NSMMS), Tampa, FL, June 25–28, 2012.

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Tomboulian, B.N.; Mason, L.S.; and Hyers, R.W.: "Lightweight Carbon Fiber Radiator for High-Temperature Nuclear Electric Powered Spacecraft," *Proceedings of Nuclear and Emerging Technologies for Space 2013*, Paper 6752, Albuquerque, NM, February 25–28, 2013.

Tomboulian, B.N.; and Hyers, R.W.: High-Temperature Carbon Fiber Radiator for Nuclear Electric Power and Propulsion: Project Overview and Update, *Proceedings of Nuclear and Emerging Technologies for Space 2014*, Infinity Science Center, MS, February 24–26, 2014.

Craven, P.D.; SanSoucie, M.P.; Tomboulian, B.N.; Rogers, J.R.; and Hyers, R.W.: "*Lightweight Damage Tolerant Radiators for In-Space Nuclear Electric Power and Propulsion*," National Space & Missile Materials Symposium (NSMMS/CRASTE), Huntsville, AL, June 23–26, 2014.

Tomboulian, B.N.: "*Lightweight, High-Temperature Radiator for In-Space Nuclear-Electric Power and Propulsion*," Ph.D. Dissertation, University of Massachusetts Amherst, 2014.