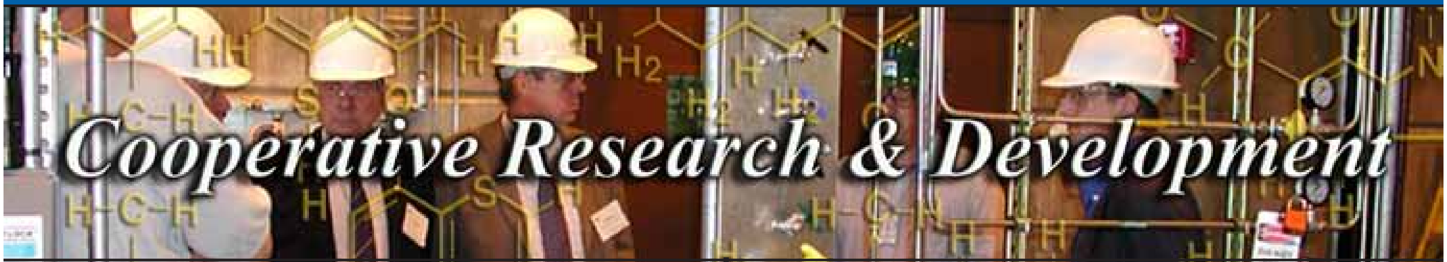
U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory



Successes

Development of Continuous Silicon Carbide Composites

Advanced Research

To support coal and power systems development, NETL's Advanced Research Program conducts a range of pre-competitive research focused on breakthroughs in materials and processes, coal utilization science, sensors and controls, computational energy science, and bioprocessing—opening new avenues to gains in power plant efficiency, reliability, and environmental quality. NETL also sponsors cooperative educational initiatives in University Coal Research, Historically Black Colleges and Universities, and Other Minority Institutions.

Accomplishments

- ✓ Process improvement
- ✓ Cost reduction
- ✓ Greater efficiency
- ✓ Advanced materials

Introduction

Through a cooperative research and development (R&D) agreement with the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL), the University of North Dakota Energy & Environmental Research Center (EERC) has been developing and testing technologies to improve the efficiency of, and reduce emissions from, fossil energy systems, including the development and testing of high-temperature materials for advanced power systems. In one of the many subtasks under this agreement, a new way of making continuous microporous silicon carbide composites was developed. This process has potential applications in diverse fields from power generation systems to automobile engines to spaceflight, as will be seen.

Commercial Need

In order for future energy systems to operate at the highest possible efficiencies, materials within them must operate at much higher temperatures than today's systems. For the construction of key subsystems such as turbines and heat exchangers, oxide dispersion-strengthened alloys are useful up to approximately 1,100°C. To reach even higher operating temperatures, advanced structural ceramics must be employed. Silicon carbide (SiC) is one such ceramic. SiC has a very high heat-transfer coefficient, is extremely hard and lightweight, and is useful to temperatures of over 1,400°C in an oxidizing atmosphere.

Current Approaches

Instead of melting to a liquid upon heating, SiC sublimes—transforming directly from solid to gas—at over 2,000°C; therefore, sintering or fusing SiC powders into structures requires very expensive furnaces and a great deal of energy. Another method of making SiC structures is through reaction bonding, which typically involves surrounding a porous carbon preform with silicon paste, then heating in a furnace until the silicon melts and flows into the preform, reacting with it to form SiC. This technique can be done at much lower temperatures than direct sintering, so that energy and capital costs are reduced. However, the method inherently leaves continuous channels of unreacted silicon metal that weaken the joint or structure at temperatures above 1,200°C and make it much more prone to corrosion at even lower temperatures. The EERC's project focus was to develop a new reaction bonding method for creating SiC structures that would maintain strength up to the maximum usable temperature of sintered SiC—over 1,400°C in an oxidizing atmosphere.

Technical Description

The EERC approach involved a careful study of the reaction mechanisms between silicon and carbon to design improved precursor mixtures and processing methods. A unique reaction bonding process was developed under this activity that produced SiC that maintained its strength to at least 1,450°C. This is much higher than any other reaction bonding technique. The material is also approximately 35 percent porous, allowing it to be infiltrated with a second phase such as a polymer or a metal to make a composite. This unique material production method allowed for the creation of near-net-shape, continuous but porous SiC composites.

Commercial Opportunities

Possible fossil energy-related applications for the EERC SiC material include its use in heat exchangers that could produce working fluids at up to 1,250°C, automobile engine blocks, turbine shrouds, turbine blades, extremely hard self-lubricating bearings, fuel grinders, and valve liners, and for impact protection. However, the material could possibly also be used in two space travel technologies.

Spacecraft Protection – One of these technologies is spacecraft protection from impact by meteoroids or space debris. The best shields would be harder than the projectiles to ensure that they are vaporized upon impact. The hardest materials are ceramics. However, they are prone to shatter when impacted. EERC's material, infused with a metal or polymer, would provide the stopping power of a ceramic, but with much less spallation or breakup than other ceramics. It would form part of a protection system known as a Whipple shield, creating a thin "bumper" or impact surface. Below it would be a gap to allow the vapor cloud to expand, and then a thin aluminum or fiber composite layer to catch the hypersonic vapor. Testing in a hypervelocity impact chamber would be necessary to determine whether or not this concept is viable.

Heat Shield – A second possible use is as a heat shield. Two principal types are currently employed, ablative and nonablative. Ablative shields, like those use in early manned spaceflight, are composed of phenolic resins that partially decompose and carbonize during reentry, taking away some of the heat that would normally build up on the surface. One problem with ablative shields is that they do not necessarily ablate uniformly, slightly changing the shape of the surface. This shape change could be especially troublesome in a long aerobraking maneuver of the type used to put the Galileo spacecraft into orbit around Jupiter. By changing shape, the aerodynamics are changed, making the prediction of the flight path more difficult. Nonablative heat shields such as the black tiles on the Space Shuttle do not change shape, but they are prone to breakage and can potentially become much hotter than ablative shields. This higher temperature could be especially problematic in high-energy returns or long aerobraking maneuvers. EERC's polymer-infiltrated porous SiC is essentially a combination of the two. It has a fixed SiC surface but could be infused with phenolic resin, which would vaporize to carry away some heat.

International Space Station Experiment – In order to determine whether the SiC composite would be stable for long periods in space while exposed to intense ultraviolet radiation (and atomic oxygen in low-earth orbit), eight coupons of the material have been included in the Materials International Space Station Experiment No. 6 (MISSE-6) (see Figure 1).

Figure 1 – Astronaut placing samples to be exposed to space environment (photo courtesy of NASA).

Project Duration

Start Date
April 2001

End Date
June 2006

Cost

Total Project Value
$336,000

DOE/Non-DOE Share
$336,000 / $0

Industrial Partners

Energy & Environmental Research Center (EERC)
Grand Forks, ND

Sioux Manufacturing Corporation
Fort Totten, ND

Ashland Chemical Company
Philadelphia, PA

Launched on the Space Shuttle Endeavour on March 11, 2008 (see Figure 2), the experiment consists of two suitcases inside of which dozens of coupons of various materials are mounted. Eleven days after launch, the experiments were attached to the exterior of the Columbus module of the International Space Station (see Figure 3). They were then opened, exposing one side of each suitcase to atomic oxygen and ultraviolet radiation on the leading side, and ultraviolet radiation on the trailing side. They will remain in orbit approximately one year, during which they will make 6,000 orbits and travel 150 million miles before being retrieved during a future Shuttle mission and returned to Earth for analysis.

EERC JH32602

Figure 2 – Space Shuttle Endeavour launch, March 11, 2008 (photo courtesy of NASA).

EERC JH32603

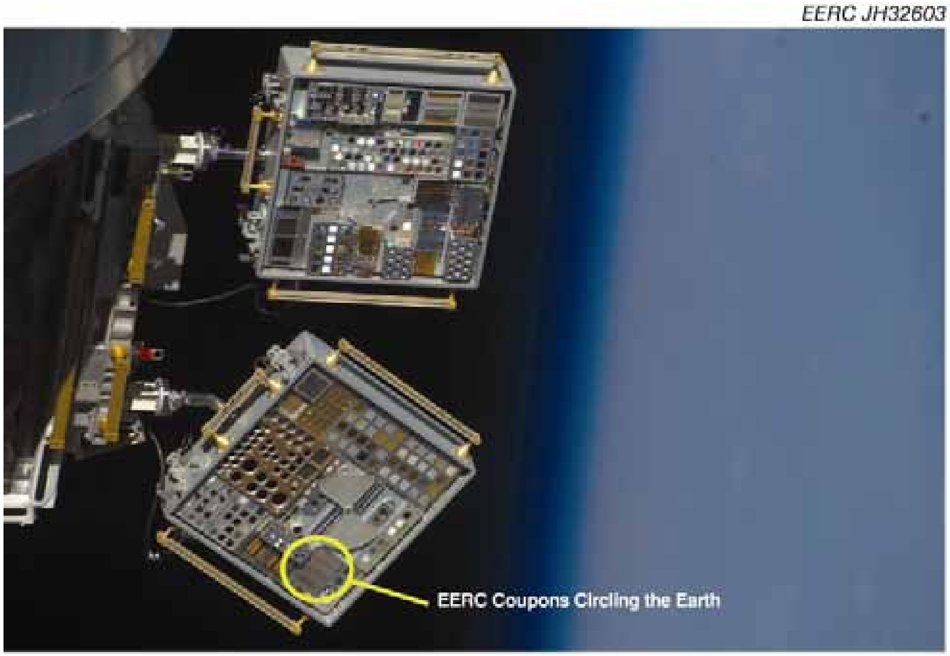


Figure 3 – Actual photo of deployed MISSE experiments taken from the Space Shuttle Endeavour (photo courtesy of NASA).

"Possible fossil energy-related applications for the EERC SiC material include its use in heat exchangers that could produce working fluids at up to 1250 °C, automobile engine blocks, turbine shrouds, turbine blades, extremely hard self-lubricating bearings, fuel grinders, and valve liners and for impact protection. However, the material could possibly also be used in two space travel technologies."

States and Localities Impacted

Grand Forks, ND

Fort Totten, ND

Philadelphia, PA

National Energy Technology Laboratory

1450 Queen Avenue SW
Albany, OR 97321-2198
541-967-5892

2175 University Avenue South, Suite 201
Fairbanks, AK 99709
907-452-2559

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

One West Third Street, Suite 1400
Tulsa, OK 74103-3519
918-699-2000

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681

U.S. Department of Energy
Office of Fossil Energy

Printed in the United States on recycled paper

June 2008

Contacts

Robert R. Romanosky
Technology Manager,
Advanced Research
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4721
robert.romanosky@netl.doe.gov

Richard B. Read
Project Manager
National Energy Technology Laboratory
626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-5721
richard.read@netl.doe.gov

John P. Hurley
Principal Investigator
Energy & Environmental Research Center (EERC)
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018
701-777-5159
jhurley@eerc.und.nodak.edu