CFCC Program

U.S. industry has a critical need for materials that are light, strong, corrosion resistant, and capable of performing in high-temperature environments. Although many ceramics perform well at considerably higher temperatures than conventional metal alloys, they are generally brittle and as a result can exhibit catastrophic failure in service. Companies are now developing continuous fiber ceramic composites (CFCCs) to overcome this limitation.

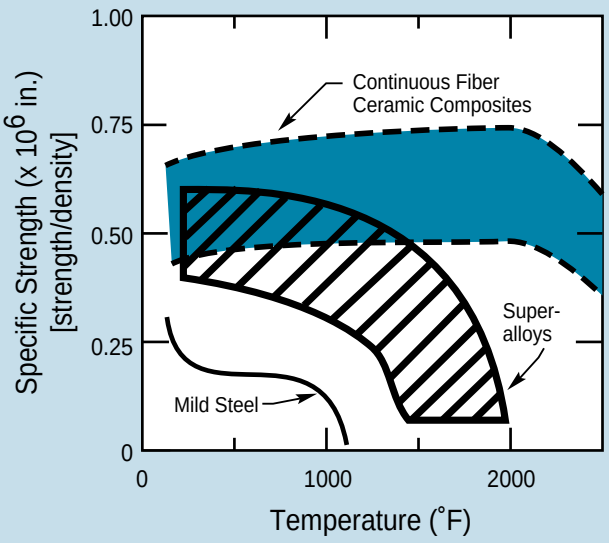
Embedded continuous ceramic fibers reinforce the ceramic matrix by deflecting and bridging fractures. CFCCs offer all the advantages of ceramics—resistance to heat, erosion, and chemical activity—while adding toughness and thermal shock resistance. Because of these enhanced properties, CFCCs are recognized as a new generation of materials for use in many industrial applications.

The U.S. Department of Energy's Office of Industrial Technologies initiated the CFCC Program in 1992 as a collaborative effort between industry, national laboratories, universities, and government. The goal is to advance processing methods for reliable and cost- effective ceramic composite materials to a point at which industry will assume the full risk of development and commercialization. Participation by industry is vital and ensures that the research agenda is market driven rather than technology driven.

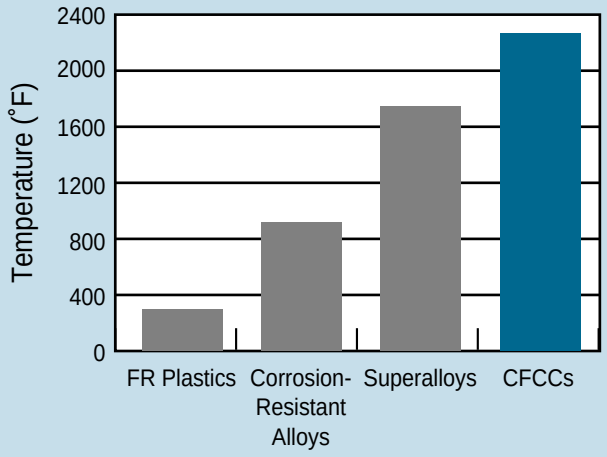
The CFCCs under development support the Industries of the Future Program, including chemical, aluminum, metal casting, forest products, glass, and steel. Industries that use CFCC components in their applications will realize substantial energy, economic, and environmental benefits, including lower maintenance, higher efficiency, and decreased operating costs. The benefits from successful CFCC commercialization are strong incentives for industry and government to conduct major R&D efforts.

By carefully focusing support, this research has stimulated both the development of standards necessary for commercialization and export, and the education of the next generation of designers, so that they will be on the cutting edge of advanced materials. Successful development and commercialization of CFCCs will enable U.S. industry to lead this market in the global environment.

CFCCs Retain Strength at Elevated Temperatures



Potential Operating Temperature Regimes Based on Corrosion in Waste Incinerators



CFCC Program Participants

AlliedSignal Aerospace Company

This team is developing methods for the fabrication of a CFCC low-heat-rejection diesel engine exhaust valve guide that is self-lubricating. The material consists of a chopped carbon fiber-reinforced silicon nitride ceramic composite. Researchers use cold isostatic pressing to form the composite valve guides and glass encapsulation hot isostatic pressing to densify them. (Douglas Twait, 310/512-2608.)

Dow Corning Corporation

Dow Corning's team uses a versatile polymer impregnation and pyrolysis process to fabricate large, complex-shaped composites. CFCC components fabricated by this process, such as gas turbine combustor liners, interstage seals, and pipe hangers, exhibit high strength and tough composite behavior to 2200˚F. (Andrew Szweda, 517/496-4558)

Du Pont Lanxide Composites Incorporated

One team is constructing silicon carbide CFCC components using a chemical vapor infiltration (CVI) process including joining of CFCCs. A second team is fabricating silicon carbide and alumina fiber-reinforced alumina matrix composites using the directed metal oxidation process (DIMOX™). Components under consideration include CFCC heat exchanger tubes, gas turbine combustor liners and shrouds, porous radiant surface burner reverberatory screens, and thin sheet recuperator elements. (Phillip Craig, 302/456-6577)

General Electric Company

The GE industry team is developing a Toughened Silcomp™ ceramic composite material consisting of continuous silicon carbide fibers in a matrix of silicon carbide and silicon. The material's lack of porosity gives the composite good oxidation resistance and thermal and mechanical properties. This CFCC material is well suited for land-based gas turbine combustor liners and shrouds. (Krishan L. Luthra, 518/387-6348)

McDermott Technologies, Inc.

McDermott's team uses a powder slurry and sol-gel impregnation process (a liquid precursor converted to solids). This technique is ideal for oxide-based composite systems and allows scaling for cost-effective manufacturing operations. Applications include CFCC gas turbine combustor liners, heat exchanger tubes, hot gas filters, and boiler components. (Richard Goettler, 804/552-6418)

Oak Ridge National Laboratory

ORNL and universities conduct generic research in the areas of environmental testing, interface development, and codes and standards. They develop the necessary supporting technologies to design, analyze, and test the materials, processing methods, and components under development in the CFCC Program. (Michael Karnitz, 423/574-5150)

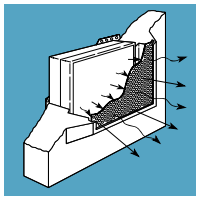
Textron Systems Division

This team is developing and demonstrating the use of silicon carbide reinforcing fibers in a nitride-bonded silicon carbide matrix to fabricate tubular structures. These tubes may be coated or infiltrated, if necessary, to enhance durability. The CFCC tubes are targeted for use in metals melting and handling, furnace radiant heaters, and combustion components for small stationary gas turbines. (William Darden, 978/452-8961)

Team Members from 17 States

ABB Combustion Engineering, CT
Advanced Ceramics, OH
AlliedSignal Aerospace Company, CA
Alzeta Corporation, CA
Argonne National Laboratory, IL
Babcock & Wilcox Company, OH
Caterpillar Incorporated, IL
Chevron Research & Technology Company, CA
Clarkson University, NY
Cleveland State University, OH
Dow Corning Corporation, MI
Du Pont Lanxide Composites, DE
Foster Wheeler Development Corporation, NJ
Frank W. Schaefer Company, OH
General Electric Company, NY
Hauck Manufacturing Company, PA
Hypertherm, CA
IBIS Associates, MA
Industrial Fiber and Pump, IL
Massachusetts Institute of Technology, MA
Materials Sciences Corporation, PA
McDermott Technologies, Inc., VA
Montana Science & Technology Consortium, MT
MSNW, Incorporated, CA
National Institute of Standards & Technology, MD
North Carolina A&T State University, NC
Northwestern University, IL
Nova Industrial Ceramics, MA
Oak Ridge National Laboratory, TN
Ohio State University, OH
Pennsylvania State University, PA
Solar Turbines Incorporated, CA
Southern California Gas, CA
Stone & Webster Engineering Corporation, MA
Sundstrand Aerospace, IL
Surface Combustion Incorporated, OH
Synterials, VA
Textron Systems Division, MA
U.S. Department of Energy, DC
University of Dayton Research Institute, OH
University of Washington, WA
University of Tennessee, TN
University of Virginia, VA
University of Cincinnati, OH
Virginia Polytechnic Institute & State U., VA
Westinghouse Electric Company, PA
Williams International, MI

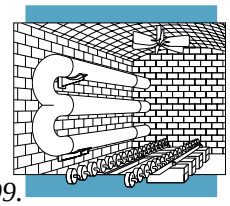
CFCC Applications & Benefits



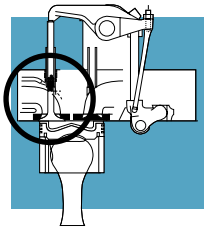
Porous Radiant Burner

Porous surface burners are an excellent source of radiant heat used in boilers, indirect drying, and process heating. CFCC materials combined with the low emissions capabilities of radiant burners will improve process efficiency and provide industry with a cost-effective means to meet Clean Air Act requirements (because of low-NO_x). A CFCC reverberatory screen, a single-layer porous mesh, mounted directly above the burner surface, will increase radiant heat output by 50%, reduce fuel consumption by 33%, and protect the burner surface. Researchers have conducted rig tests of the CFCC screen for up to 15,000 on-off cycles without failure. Burners incorporating the reverberatory screens will be installed in industrial plants in 1998, and new industrial applications are being evaluated. *Projected date of commercialization: 1999.*

Tubular Radiant Burners



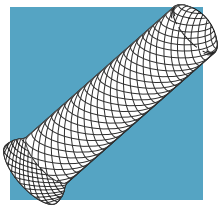
Higher temperature capability and longer life tubular radiant burners are required to meet future metal processing industry needs. Both metal heat-treating and melting applications can benefit from the increased temperature capability and operating efficiency of radiant burners using CFCC components. These composites can extend the temperature range for using fossil fuels for indirect heating applications. Another benefit is that operating costs for a furnace can be reduced due to decrease in downtime/maintenance. *Projected date of commercialization: 1999.*



Diesel Engine Valve Guides

The primary life limitation of diesel engines operating on natural gas is wear on valve guides and valve stems. Tests have demonstrated that CFCC materials provide a low-friction interface, wear at a much lower rate than metals, and result in decreased wear on the valve stem. A CFCC self-lubricating valve guide will solve wear and pollution problems, increase fuel efficiency by 30%, increase engine reliability, and reduce particle emissions by 25%. This CFCC guide is crucial to future development of low heat rejection diesel engines, which are targeted for stationary and mobile applications. *Projected date of commercialization: 2000.*

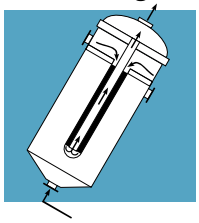
Hot Gas Filters



Hot gas candle filters, porous closed-end tubes, remove fine coal ash particles in pressurized fluidized bed combustion systems and coal gasification systems. Filters can also be used for particulate removal in the chemical and refining industries. CFCC filters are being evaluated for contaminant removal in streams operating at 600 to 1800˚F. Due to their toughness and thermal shock resistance, CFCCs overcome current filter failures, such as the inability to survive back-pressure pulses used for cleaning. CFCC cleaning systems will reduce emissions and costs, increase product yield and efficiency, and protect downstream equipment from wear. *Projected date of commercialization: 2000+.*

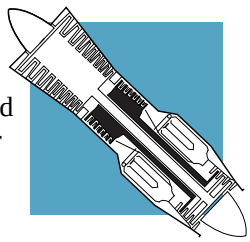
High-Pressure Heat Exchanger Tubes

Heat exchangers transfer heat from dirty flue gases to clean gas stream, thus protecting turbine machinery from direct exposure to the hostile flue gas stream. Ceramic heat exchangers are more efficient than metallic ones because the exhaust gas does not have to be



cooled before passing through the heat exchanger. CFCC materials are corrosion and thermal shock resistant, and will allow higher heat exchanger temperatures and less natural gas heating than metals. Increased temperatures will lead to faster reaction rates, higher pressures will lead to increased throughput, corrosion resistance will lead to longer life, and all these factors lead to greater efficiency and lower costs. In one application, a CFCC gas preheater increased overall efficiencies from 35% to 47%. Similar process industry component evaluations include high alkalai particle separators, tube shields, and pump cans. *Projected date of commercialization: 2000.*

Gas Turbine Combustor Liners and Shrouds



Gas turbine engines are critical to our infrastructure of power generation, cogeneration, and transportation. A key component of gas turbine engines is the combustor, where fuel and air are mixed and ignited. Using CFCC combustor liners will reduce or eliminate the cooling air that is necessary when using current metal liners. This alone will increase turbine efficiency by 0.5%, reduce NO_x and CO emissions, and decrease maintenance time and operating costs. A 1000-hour field test at ARCO Western Energy has demonstrated ceramic composite combustor liners to be an integral part of a cost-effective emissions prevention strategy for gas turbines, reducing NO_x and CO to allowable limits without the high maintenance costs and performance penalties of water injection.

The shroud of a large turbine is a stationary component concentric to the outer diameter of the rotor blades. A CFCC tip shroud could reach operating temperatures of 2350˚F. While metal shrouds require cooling, analysis indicates that the higher temperature capability of CFCC materials will reduce cooling flow to 0.25%. This will increase power output, reduce energy consumption, and reduce emissions by 10 to 25%. *Projected date of commercialization: 2000+.*

Industry Focus

Aluminum
- Immersion burners for aluminum holding furnaces
  Textron Systems Division

Chemicals
- Hot gas filters
  Dow Corning
- Tubes for reformers
  Du Pont Lanxide Composites
- Radiant burners for curing coatings
  Du Pont Lanxide Composites
- High alkalai particle separator
  Du Pont Lanxide Composites

Forest Products
- Boiler components
  McDermott Technologies, Inc.
- Radiant burners for paper drying and coatings
  Du Pont Lanxide Composites,
  McDermott Technologies, Inc.

Glass
- Radiant burners for heat-treating glass products
  Du Pont Lanxide Composites

Metal Casting
- Immersion tube heaters
  Textron Systems Division

Refining
- Pipe hangers
  Dow Corning

Cross Cutting
- Stationary diesel engine components
  AlliedSignal Aerospace
- Gas turbine engine components
  Du Pont Lanxide Composites,
  General Electric,
  Dow Corning
- Heat exchangers
  McDermott Technologies, Inc.,
  Du Pont Lanxide Composites
- Hot gas filters
  McDermott Technologies, Inc.

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- **Bibliography of Publications from the CFCC Program**, Oak Ridge National Laboratory, September 1997
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