Ceramic Engineering & Science Proceedings

Issue 4, 1996

Proceedings of the
20th Annual Conference on
Composites, Advanced Ceramics,
Materials, and Structures—B

January 7–11, 1996
Cocoa Beach, FL

Victor Greenhut
Program Chair

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Each issue of *Ceramic Engineering and Science Proceedings* includes a collection of technical articles in a general area of interest. These articles are of practical value for the ceramic industries and the general public. The issues are based on the proceedings of a conference. Both American Ceramic Society and non-Society conferences provide these technical articles. Each issue is organized by an editor who selects and edits material from the conference proceedings. The opinions expressed are entirely those of the presentors. There is no other review prior to publication.

Table of Contents

20th Annual Conference on Composites, Advanced Ceramics, Materials, and Structures — B

Interfaces and Coatings

Mechanical and Elevated Temperature Properties

ARPA's Low-Cost Ceramic Composites Program

Introduction

CMC's Research in Europe and the Future Potential of CMC's in Industry

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Abstract

CMC's (Ceramics Matrix Composites) have been developed for high temperature applications in aerospace and military industries. In general, the CMC's should be capable of outperforming the best available superalloys. Great efforts are being given to pinpoint spin-off technologies i.e. applications in modern fossil fuel power plants, gas turbines, petrochemistry etc. In these applications, the CMC's have to operate at temperatures up to 1400°C, in corrosive environments for long durations. These developments will provoke a breakthrough for this new group CMC-materials.

The paper will:

i) give an overview of the CMC's research in Europe; processing, and characterization of physical, chemical and engineering properties at high temperatures;
ii) pinpoint the R&D needs to achieve the potential growth;
iii) review the industrial potentials.

Introduction

Many challenges for improvements and new developments in energy technology and industrial productivity are not met because of the unavailability of structural materials capable of assuring safe and reliable plant operation, at competitive costs. The advanced energy technology requires materials with:

i) improved erosion - and corrosion resistance,
ii) better mechanical behaviour,
iii) higher temperature capability.

A new group of high temperature materials with engineering properties better than the best modern superalloys and metal matrix composites has to be invented. The transport industry has an additional need for light weight materials; with high stiffness and wear resistance. New materials, complimenting the use of advanced polymers and carbon composites have to be realized, to meet the severe technical specifications.

Monolithic ceramics offer combined properties of low weight, high temperature strength and environmental stability. The problem with these ceramic materials is their lack of defect tolerance, leading to the possibility of catastrophic service failure in structural components. This may result in:

i) air-trafic problems caused by for example; damaged aero engine components and
ii) in important financial losses due to unforseen shutdowns in industrial plants.

Improved ceramic processing techniques and toughening of ceramics through the incorporation of particulates, whisker and short fibers result in ceramics with better fracture toughness, but the brittle failure problem still persists.

Long fiber and woven reinforced ceramic composites have the potential to combine chemical resistance, high temperature strength and toughness. CMC's may offer a challenge for the technology of the 21st century in which the modern industry demands a combination of:

i) high temperature stability for thousands of hours,
ii) hot and ash corrosion resistance,
iii) reliable mechanical properties - in the 1200°C to 1600°C temperature range; and
iv) cost competitivety, Figs. 1 and 2.

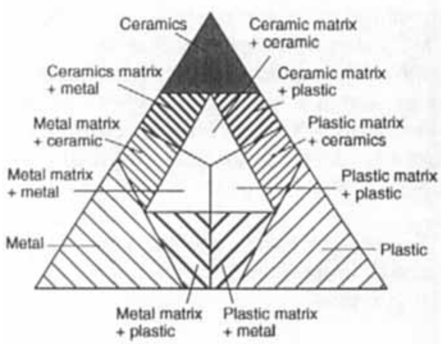

Fig.1: Different forms of composites

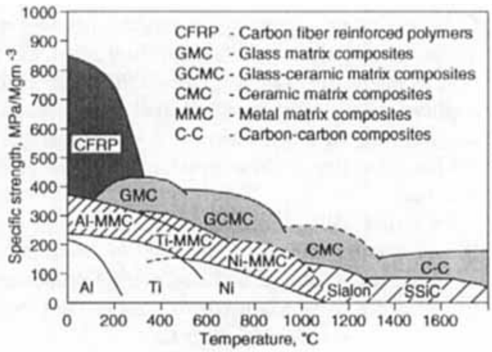

Fig.2: Strenght of structural materials

The ceramic matrix composites "C-SiC" and SiC-SiC" form the leitmotiv through the whole paper, because of the great interest in these materials by industry and the extreme difficulties to introduce them in innovative technologies. Much information available in the paper can easily be used for other ceramic- and carbon-carbon composites.

2. MANUFACTURE OF HIGH TEMPERATURE CMC-MATERIALS

A status report is given on the development of:

i) high temperature ceramic fiber reinforcements,
ii) ceramic matrices and
iii) manufacturing methods for industrial CMC's-materials.

2.1. Advanced Ceramic Fiber Reinforcements

The commercial breakthrough of CMC's strongly depends on the future of high temperature technology/industry. Therefore, continuous ceramic fiber reinforcements should have a variety of corresponding 'high temperature' properties: high stiffness at low and high temperatures, high strength, high thermal-mechanical stability, high oxidation - corrosion resistance, small diameter for CMC fabricability, and low cost for commercial viability.

Potential ceramic fibers of commercial interest for high temperature use in European industry and for research are discussed:

2.1.1. Alumina based fibers: A series of multifilament small-diameter fibers were recently made available commercially: the "Nextal 720" from 3M Company; Sumitomo's "Altex" fiber and a high purity α-alumina fiber "Almax" from Mitsui. The main advantage of oxide fibers is their chemical stability. However, internal grain growth, phase transformation and creep of polycrystalline fibers limit their working temperature to a maximum of 1200°C. Superior creep resistance can be obtained by the use of monofilament large - diameter fibers, for example the single crystal Sapphire fibers from Saphikon and the YAG (Yttrium Aluminum Garnet) fiber from General Atomics. They have potential for CMC service above 1200°C, however their large diameter of 140 μm prohibits weaving and low cost fibers are not available.

2.1.2. Silicon carbide based fibers: New multifilament small-diameter fibers are available: Nippon Carbon's Hi-Nicalon and Ube's Tyranno SiC-fibers are typical representatives. The new Hi-Nicalon fiber gives an increase in creep resistance of up to 200°C compared with standard SiC fibers. The small diameter fiber of roughly 10 μm allows weaving into two and three - dimensional fabrics and the availability in large quantities provides industrial production of high quality CMC-materials. Tyranno fibers, with only 13% oxygen also offers better engineering properties.

Above their thermal stability threshold of about 1100°C degradation rapidly occurs primarily by recrystallisation and crystal growth, and additionally through internal oxidation due to the residual oxygen context. Developments focussed on the reduction of both effects have resulted in a series of new fiber types with improved properties. Nippon "Hi-Nicalon S" fiber; powder derived and sintered α-SiC fiber from Carborundum and a polymer derived and sintered ß-SiC fiber from Dow Corning. The new fibers have excellent thermal stability - up to 1200°C, with high elastic modulus of 420 GPa, higher temperature creep and corrosion resistance than the commercially available fibers and are potential candidates for the reinforcement of CMC's in the 1200°C to 1400°C temperature range.

Monofilaments "100 to 140 μm" diameter CVD-SiC fibers are produced. They currently offer the best combination of creep and rupture strength and corrosion resistance. Typical examples are the Textron Specialty Materials (TSM) - SCS-6 and the DRA-Sigma fibers. The newly developed TSM-SCS-2 with 50 μm diameter, is especially promising.

2.1.3. Silicon nitride based fibers: Latest developments are focussed on improved products of silicon nitride and derivatives. Examples are the Tonen corporation Si_3N_4 fibers; the Dow Corning silicon nitride carbide fibers and the single phase Si-B-(N,C) fibers of Bayer A.G. The forecast is that continuous ceramic fibers will be produced with outstanding oxidation resistance (up to 1600°C) and with considerably improved mechanical performance at high temperatures (crystallization resistance up to 1800°C). The commercial availability is long term.