

## **RECENT SCIENTIFIC HISTORY OF THE BIOMIMETIC AND MULTIFUNCTIONAL MATERIALS GROUP (as of November 2005)**

The Biomimetic and Multifunctional Materials Group has 18 members. Among them, there are ten Ph. D. (a Full Professor, six Assistant Professors, two hired under contracts, and an I+D director of Solucar Energía, part of Abengoa), as well as 7 pre-doctoral students.

The most prominent activities of the group are detailed below.

### **SCIENTIFIC PRODUCTION OF THE GROUP ON THE LAST FIVE YEARS**

- **Papers:** 124 articles, of which 113 are published and 11 accepted or in print.
- **Books:** 2.
- **Book chapters:** 8.
- **Patents:** 5.
- **Congress Proceedings participations:** 76.
- **Ph. D. Theses:** 4 already obtained + 4 being directed.
- **Journal Scientific Committee Memberships:** 2  
Boletín de la Sociedad Española de Cerámica y Vidrio  
Journal of the European Ceramic Society

### **FUNDING OF THE GROUP IN THE LAST FIVE YEARS**

#### **Projects, contracts and specific agreements:**

- 7 I+D contracts
- 14 directed I+D projects (plus 5 non-directed)
- 2 specific agreements
- 3 specific fundings

Globally, the group has obtained 985.789,60 € in funding over the last five years.

## **MOST PROMINENT RESEARCH AREAS**

### **I. BIOMIMETIC SILICON CARBIDE CERAMICS**

#### **Synthesis optimization**

- Evaluation of the optimal pyrolysis temperature and atmosphere.
- Study of the infiltration temperature and of its possible lowering by using silicon alloys.
- Infiltration atmosphere: replacement of vacuum with inert gas fluxes.
- Evaluation of new processes for reactive infiltration, such as Ti for TiC formation.
- Use of new, cellulose-based precursors.
- Final biomorphic SiC re-infiltration with metals in order to obtain Cermet interlocked structures.

#### **Determination of formation mechanisms and of the mechanical behavior**

#### **Development of specifically-targeted biomimetic ceramics**

- STRUCTURAL APPLICATIONS
  - Cutting tools
  - Electrical resistances
  - Heat interchangers
  - Structural reinforcements
  - Electrical motor contacts
  - Braking elements
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- BIOTECH APPLICATIONS
  - Medical implants
  - Cellular reactors
  - Live-tissue support

SiC biomorphic materials stand out as a new family of ceramics with a wide array of possible uses. Compared with the traditionally used hot-sintering method, SiC fabrication via pyrolysis and infiltration of Si on wood is much more versatile, so that high-resistance, low-cost materials may be obtained with complex microstructures and precisely machined shapes.

In pursuit of this goal –mimicking natural structures–, and with the funding of the **FEDER 1FD972335** project, a lab for SiC-processing via infiltration of liquid silicon in carbon preforms obtained out of wood pyrolysis was established at the

University of Seville on 2000. An exhaustive trial period ensued, and possible combinations of wood, shapes and processing methods are researched in depth. The obtained results were very encouraging, allowing for a complete definition of the optimal technique (temperatures, heating gradients, treatment duration, microstructures...) which lead to two patent applications: for Spain (2001) and international (2002).

This success has given rise to a good deal of working lines for scientific investigations, as well as a thriving number of national and international collaborations for physical and microstructural characterization of these new materials (**PETRI PTR19950613OP, MAT200210590E, MAT200305202C0201, Integrated Action HA20010076**). Simultaneously, a rich exchange with several businesses has been set up (supported by the Technological Transference Project 2001/737, Junta de Andalucía) in order to identify potential applications for the new product. Under these technology transference actions, the following **applications** for the ceramic material have been tested:

- Reinforcements for concrete in aggressive environments (financed by Project **PETRI PTR19950613OP**, collaboration with ALFRAN S.L.)
- High-temperature filters (collaboration with Slee Corp, EE.UU.)
- Low-density structures for medical implants (financed by Contract **OG083/02**, with the University of Vigo, Spain)
- Joints and assembly pieces for wood structures and bathroom fittings (collaboration with the Institute of Wood).
- Electrical resistors (collaboration with the Ioffe Institute, Russia).
- Heat exchangers in solar power centrals (collaboration with INABENSA S.A. under Project **PROFIT FIT0300002004282** and Contract **OG143/04**, and with SOLUCAR ENERGÍA S.A. under Contract **OG144/04**).
- Components susceptible of friction, such as brake pads, dynamo commutator contacts or high-temperature joints
- Ballistic protection (collaboration with the Polytechnical University of Madrid)
- Acoustic and thermal isolation
- Cutting elements

## II. CHARACTERIZATION OF CERAMIC AND LAMINATED COMPOSITES FOR STRUCTURAL APPLICATIONS

### Eutectic composites $ZrO_2(Y_2O_3)/Al_2O_3$ , $ZrO_2/YAG/Al_2O_3$

- Characterization of: defects caused by fabrication and by plastic deformation; crystallographical orientation; microstructural stability; phase and precipitate distribution
- Influence of temperature on resistance to plastic deformation and creep
- Determination of high-temperature plastic deformation micromechanisms; correlation with processing and microstructure

### Layered materials: metallic alloys with a ceramic $ZrO_2/Al_2O_3$ cover layer

- Characterization, microstructural stability, topology, composition and crystalline structure, both for each of the layers and for metal-ceramic and ceramic-ceramic boundaries

This research line has been developed with funding from the following projects:

- "Microstructural Characterization of Laser-Processed Advanced Structural Ceramics" (**CICYT MAT20001533C0303**)
- "Development of a Modular System for High-Temperature Ceramic Materials Characterization" (**MCyT PROFIT FIT0201002003359**, Contracts **OG110/03** and **OG145/04**)
- "Microstructural Characterization of Ceramic and Layered Composites for Structural Applications" (**MCyT MAT200306085C0303**)

## III. HIGH-TEMPERATURE PROTON EXCHANGE MEMBRANES

- Fabrication of proton exchange membranes via solid-state reaction.
- Measurement of mechanical properties in a wide range of temperatures, tensions and  $O_2$  partial pressures.
- Development of a microscopical model to explain the interaction and transport of point defects, allowing for an improvement on mechanical properties and conductivity.
- Implementation of the fabricated membranes in fuel cells (collaboration with Hynergreen S.A.).

Preliminary research work has been supported by "European Office of Aerospace Research and Development" and "Air Force Office of Scientific Research" through a Joint Project (No. 024001; "High Temperature Protonic Conductors by Melt Growth", 200206, 200.000 USD) involving University of Seville, Ecole des Mines (Francia), Commissariat à l'Energie Atomique (Francia) and NASA Glenn

Research Center (EE.UU.), whose coordinator and main researcher is Julián Martínez Fernández.

A new project proposal, "Development of highly-efficient, durable fuel cells" (Junta Andalucía 787) is currently being evaluated by the Junta de Andalucía.

#### **IV. MAGNETIC MICROWIRE CHARACTERIZATION**

- Study of ambient-temperature recrystallization and mechanical properties

A collaboration with Prof. Julián González's group (University of the Basque Country) has been carried out within this research line, in order to perform a microstructural and mechanical characterization of magnetic microwires.

#### **RELEVANT PAPERS PUBLISHED IN THE LAST FIVE YEARS**

- Morscher G.N., and Martínez Fernández J.,  
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J. Am. Ceram. Soc Vol. 82[1] pp. 14555 (1999)
- Gallardo López A., Muñoz A., Martínez-Fernández J., Domínguez Rodríguez A.  
"High Temperature Creep of Liquid Phase Sintered Silicon Carbide"  
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- Gómez García D., Martínez Fernández J., Domínguez Rodríguez A. and Westmacott K. H.  
"On the Influence of the Heat Treatments in Reducing Atmosphere on the Mechanical Behaviour of Ytria Fullystabilized Zirconia Single Crystals"  
Phil. Mag. A. 79[8] pp. 18391852 (1999).
- Morscher G.N. and Martínez-Fernández J  
"Room and Elevated Temperature Tensile Properties of Single Tow HiNicalon,  
Carbon Interphase, CVI SiC Matrix Minicomposites"  
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- Martínez Fernández J., Muñoz A., Valera-Feria F.M. and Singh M.  
"Interfacial and Thermomechanical Characterization of Reaction Formed Joints in Silicon Carbide Based Materials"  
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- A.R. de Arellano-López, J.J. Meléndez-Martínez, A. Domínguez-Rodríguez, J.L. Routbort,  
H.T. Lin, P.F. Becher  
"Grain Size Effect on Compressive Creep of SiC whiskerreinforced Al<sub>2</sub>O<sub>3</sub>"

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- Gómez D., Martínez Fernández J., y Domínguez Rodríguez A.  
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Journal of the European Ceramic Society Vol. 22 [16] pp. 28212825 (2002).
- Bravo León, Y. Morikawa, M. Kawahara y M. J. Mayo  
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"Creep of Mullite Containg Y2O3"  
Acta Materialia 50 (2002) 43254338
- J. Martínez Fernández, S. Farmer y, A. Sayir,  
"High temperature creep of directionally solidified  $Al_2O_3/Er_3Al_5O_{12}$  fibers".  
Acta Materialia Vol 51 [6] pp 1705–1720, (2003).
- B. I. Smirnov, Y. A. Burenkov, B. K. Kardashev, F. M. Varela Feria, J. Martínez Fernández, A. R. de Arellano-López.  
"Temperature Dependences of Young's Modulus of Biomorphic Silicon Carbide Ceramics"  
Physics of the Solid State, Vol 45, No 3, pp. 482485 (2003)
- P. González, J. Serra, S. Liste, S. Chiussi, B. León, M. Pérez-Amor, J. Martínez-Fernández, A. R. de Arellano-López, F.M. Varela-Feria  
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 J.D. French and K J. Yoon  
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 Journal European Ceramic Society, Vol. 22 [1415] (2002).