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13. ABSTRACT (Maximum 200 words) An international workshop on Fracture of High Performance Fibers was held in November 2000 in Palma de Malloca, Spain. The performance of high temperature composites is dependent on understanding the mechanical properties of fibers. Many aspects of the controlling mechanisms of fiber fracture are unknown and this workshop brought together an interdisciplinary team of scientists and engineers from the United States and Europe to discuss the latest research in this field. This provided a unique opportunity to capture the current state of knowledge on fiber fracture mechanisms. A publication is anticipated by December 2001 entitled "Fracture of High Performance Fibers" edited by Professors Elices, Llorca, and Sayir.					
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CASE WESTERN RESERVE UNIVERSITY

Dr. Joan Fuller
 Ceramic Material Program Manager - AFOSR/NA
 801 N. Randolph Street, Rm. 732
 Arlington, VA 22203-1977

September 4, 2001

Dear Joan,

An international workshop on *Fracture of High Performance Fibers* was conducted during November 2000, in Palma de Mallorca, Spain, under the sponsorship of the European Science Foundation (ESF), with the aid from NASA Glenn, United States Air Force Office for Scientific Research, DuPont and Spanish Ministry of Education (CICYT). The partial funding for this workshop has been provided by Air Force Office of Scientific Research with the project title *Workshop on Fiber Fracture (F#49620-00-1-0115)* through CWRU.

The meeting was successful and contributed through the organization of an interdisciplinary workshop on *fracture of fibers*. The contact among the researchers working in different fields are increased. There is not doubt that successful ideas in the development of a kind of fibers lead to cross fertilization in another fields. Two types of oral contributions were presented at the meeting: overview lectures and contributed talks on current research issues in this area. The overview lectures will be published as a book entitled "Fracture of High Performance Fibres" that was edited by Profs. Elices, Llorca and Sayir. The editorial and the content page are enclosed. The contributed talks will be summarized in the special issue of Engineering Fracture Mechanics. The book and special issue of Engineering Fracture Mechanics is expected to be published in December 2001.

In summary, I would like to ask you to consider the enclosed documents as a final report of this project and consider the workshop as a success from different perspectives. I thank you for the participation of the important area of research.

Best Regards,

Ali Sayir, Ph. D.

Enclosed:
 Editorial
 Content of the book entitled Fiber fracture
 Workshop Justification

cc. Derek Hunprey / CWRU

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FRACTURE OF HIGH PERFORMANCE FIBRES

EDITORIAL

Fibres rank among the stiffest and strongest materials either manufactured by man or present in nature. Fibres are used in structural components on their own or they are embedded in a matrix to form composite materials. Fibre reinforced composites occupy a central role in the development of new materials and overcome many of the limitations of traditional materials.

Great progress has been made in the development of fibers and considerable advances can be expected by exploiting the knowledge that exists at present concerning the relationships between fiber surface and matrix. However, less attention has been paid to fracture mechanisms of high performance fibres. In support of this important area of research, the international workshop on this topic was conducted during November 2000, in Palma de Mallorca, Spain, under the sponsorship of the European Science Foundation (ESF), with the aid from NASA Glenn, United States Air Force Office for Scientific Research, DuPont and Spanish Ministry of Education (CICYT). Two types of oral contributions were presented at the meeting: overview lectures and contributed talks on current research issues in this area. This special issue is a selection of the latter, following a generous offer from the editors of Engineering Fracture Mechanics to prepare a written contribution of the talks.

The seven papers in this issue only provide a flavour of the activity in the area of fibre fracture. Papers range from sophisticated ceramic to polymer fibres and spider silks, and cover theoretical and experimental issues. Four papers put emphasis on the relationship between the macroscopic behaviour and the failure mechanisms controlling the fibre strength in ceramic fibres (SiC and $\text{Al}_2\text{O}_3/\text{ZrO}_2$), glass fibres (basalt) and silks (silkworm and spider silk). It is also worth noting that while surface flaws were critical in determining the strength of ceramic and glass fibers, natural silks exhibited a more ductile behaviour, their strength being dependent on the microstructural organization at the submicron level rather than on the flaws. The importance of surface flaws was stressed in two theoretical papers devoted to study the influence of flaw shape or flaw origin on the fibre strength using, respectively, linear elastic fracture mechanics and Weibull statistics. Finally, the last paper illustrates the use of *in situ* Raman spectroscopy to monitor damage and deformation in composites in the presence of different length scale discontinuities.

M. Elices, J. LLorca, and A. Sayir
Guest Editors

FIBRE FRACTURE

Introduction

- Chapter 1. *Overview of Fiber Fracture*
K.K. Chawla. University of Alabama. USA
- Chapter 2. *Micromechanisms of Fiber Fracture*
M. Elices, J. Llorca. Polytechnic University of Madrid. Spain
- Chapter 3. *Forms of Fiber Fracture*
J.W.S. Hearle. UMIST. UK

Ceramic Fibers

- Chapter 4. *Fracture Processes in SiC based Fibers*
A. Bunsell. Ecole de Mines, Paris. France
- Chapter 5. *Fracture Processes in Oxide Ceramic Fibers*
M.H. Berger. Ecole de Mines, Paris. France
- Chapter 6. *Fracture Characteristics of Single Crystal and Eutectic Fiber*
A. Sayir, S.C. Farmer. NASA Glenn Research Center. USA

Glass Fibers

- Chapter 7. *Fracture of Glass Fibers*
P.K. Gupta. The Ohio State University. USA

Carbon Fibers

- Chapter 8. *Fracture of Carbon Fibers*
J.G. Lavin. DuPont. USA

Metallic Fibers

- Chapter 9. *Fracture of Metallic Fibers*
H.U. Kuenzi. Eth Zürich. Switzerland
- Chapter 10. *Fracture of Superfine Metallic Wires*
K. Yoshida. Tokai University. Japan

Polymeric Fibers

- Chapter 11. *Fracture of Highly-Oriented Fibers*
J.W.S. Hearle. UMIST. UK
- Chapter 12. *Fracture of Synthetic Polymeric Fibers*
Y. Termonia. DuPont. USA
- Chapter 13. *Fracture of Natural Polymeric Fibers*
C. Viney. Heriot-Watt University. UK
- Chapter 14. *Fracture of Common Textile Fibers*
J.W.S. Hearle. UMIST. UK

Nanofibers

- Chapter 15. *Fracture of Nanotubes*
J. Bernholc. North Carolina State University. USA

WORKSHOP ON FIBER FRACTURE

1. Workshop justification

High performance materials are usually composite materials and fiber-reinforced composites stand out as those which provide the best properties. The fibers are the essential components in these materials and the knowledge of their behavior is critical to understand the response of composites as well as to develop the new design strategies which optimize their use. There are many aspects still unknown in the physical mechanisms which control *fiber fracture*. Their analysis may lead to remarkable improvements in the properties of fibers and composites, which may have significant impact for industry.

It is proposed to contribute to this effort through the organization of an interdisciplinary workshop on *fracture of fibers*. The fracture mechanisms depend on the fiber characteristics and ceramic, metallic and polymeric (either natural or synthetic) fibers exhibit very different nature and structure. The contact among the researchers working in these three fields is, however, very limited. There is no doubt that successful ideas in the development of a kind of fibers may lead to cross fertilization in another field, leading to new horizons for academic research and more competitive products for industry. It is not easy, however, to get together scientists with different background (physicists, engineers, biologists, chemists, etc.) working in the academia and in the industry, and this is one of the main purposes of the planned workshop.

In light of the imminent potential for ceramic fibers to revolutionize advanced turbine engines and aircraft, we propose a meeting to bring scientists and engineers in the European community together with US researchers in order to gain an international perspective on new developments in the high-temperature ceramics field. This will provide a state-of-the-art picture of this rapidly evolving field of study. Furthermore, US Air Force and NASA will obtain an overview of the current state of knowledge in the areas of high temperature fibers from which gaps in understanding can be identified. We will coordinate this meeting with NASA Lewis Research Center and Air Force Office of Scientific Research to achieve productive results. NASA Lewis Research Center has agreed to participate and possibly cosponsor the meeting. The proposed meeting will provide a forum for discussing the essential scientific issues involved in the development and use of high temperature materials.

2. Scientific content

In the present situation of technological development, fibers stand among the stiffest and strongest materials either present in nature or manufactured by man. They are used in structural components embedded in a matrix which maintains the fibers oriented in the optimum direction, distributes the concentrated loads, protects the fibers against wear and chemical attack from the environment, and provides the transverse stiffness to avoid buckling in compression. These new composite materials are rapidly taking over the traditional structural materials (metallic alloys and polymers) in many industrial components and new potential uses are envisaged every day. These novel applications often require further improvements in the fiber properties and the scientific meeting is proposed to contribute to this effort.

Fiber stiffness and strength come from the strong covalent, ionic or metallic bonds and the fiber microstructure is designed in such a way that most of the load is carried by these atomic or molecular links. This is achieved in *polymeric fibers* by aligning the molecular chains in the fiber direction so the stresses are supported by the C-C and C-N bonds. The deformation of *metallic fibers* also has to be accommodated by the elastic strain of the metallic bonds because the strong texture, the small grain size, and the extremely high dislocation density induced during cold drawing inhibit dislocation motion. The absence of strain accommodation mechanisms, such as chain slippage or plastic deformation, makes fibers very brittle, especially in *ceramic fibers*. Their strength is thus dictated by the longest

defect in the fiber and increases with $1/\sqrt{d}$, where d is the fiber diameter, because the physical size of the critical defects scales with the fiber diameter. In fact, the most efficient method to increase the strength of ceramic fibers, whose inherent lattice resistance to dislocation motion is very high, is to reduce the diameter and grain size.

Regardless of the fiber nature, the microstructure of stiff and strong fibers leads to brittle materials whose strength is ultimately controlled by their fracture behavior. However, the information available in the open literature on the mechanisms of fiber failure is limited. This is partially due to the fact that many interesting results are proprietary and they have not been disclosed. The meeting will bring together scientists working in the academia, research laboratories and industrial enterprises. There will be ample time for discussion in a relaxed atmosphere, which will facilitate the exchange of ideas and the dialogue.

In addition, fiber development is a paradigmatic topic in Materials Science, which needs for interdisciplinary research. This sometimes makes communication difficult, as people with different backgrounds speak different languages. In this respect, the conference will be an attractive meeting point for chemists, physicists, biologists, and engineers, who will learn from each other. This will lead to cross fertilization, where successful ideas or strategies to manufacture tougher polymeric fibers may be used to produce metallic or ceramic fibers and *viceversa*.

WORKSHOP ON FIBER FRACTURE
Sponsored by the European Science Foundation
(19-24 October, 2000)

Palma de Mallorca - Hotel Cala Viñas
(Tentative Programme)

- Thursday 19.- Venue (Afternoon)
Fiber fracture, an Overview (K. Chawla)
- Friday 20.- Fracture of ceramic fibers (oxide) (A. Bunsell, M. Berger)
Fracture of ceramic fibers (non oxide) (A. Bunsell, M. Berger)
Short communications and posters on Ceramic Fibers
- Fracture of metallic fibers
Short communications and posters on Metallic Fibers
- (Evening: Social event)
- Saturday 21.- Fracture of syntetic polymeric fibers (Y. Termonia)
Fracture of natural polymeric fibers (C. Viney)
Short communications and posters on Polymeric Fibers
- Fracture of liquid-crystal Fibers
Short communications and posters
- (Evening: Social event)
- Sunday 22.- (Half day excursion to Valldemosa and North Mallorca)
- Monday 23.- Fracture of glass fibers (P.K. Gupta)
Short communications and posters on Glass Fibers
- Fracture of carbon fibers (J.B. Donnet*)
Short communications and posters on Carbon Fibers
- Short communications and posters
- Tuesday 24.- Fracture of nanowires and nanotubes
Departure (Morning)