Final Report

to

Air Force Office of Scientific Research/NE
Bolling Air Force Base
Washington, D.C. 20332-6448
Attention: Dr. A. H. Rosenstein

on

INTERNATIONAL CONFERENCE ON MECHANICAL FATIGUE OF ADVANCED MATERIALS

13-18 January 1991

Grant No. AFOSR-90-0350

prepared by

R. O. Ritchie and R. H. Dauskardt
University of California, Berkeley

and

B. N. Cox
Rockwell International Science Center

(Conference Chairmen)

15 February 1991

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Engineering Foundation; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Same as 8a
6c. ADDRESS (City, State, and ZIP Code) 345 East 47th Street New York, NY 10017	7b. ADDRESS (City, State, and ZIP Code) Same as 8c
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Air Force Office of Scientific Research/NE; 8b. OFFICE SYMBOL (If applicable) NE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-90-0350
8c. ADDRESS (City, State, and ZIP Code) Bolling Air Force Base Washington, D.C. 20332-6448 Attn.: Dr. A. H. Rosenstein	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61102F	2306	A1	

11. TITLE (Include Security Classification)
INTERNATIONAL CONFERENCE ON MECHANICAL FATIGUE OF ADVANCED MATERIALS (Unclassified)

12. PERSONAL AUTHOR(S) RITCHIE, R. O., DAUSKARDT, R. H., Dept. of Materials Science & Mineral Eng., Univ. of California, Berkeley, CA 94720, COX, B. N., Rockwell Intl. Sci. Ctr., Thousand Oaks, CA

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 90/9/30 TO 91/6/30	February 15, 1991	24

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This document provides a description and technical summary of the International Engineering Foundation Conference on Mechanical Fatigue of Advanced Materials, held in Santa Barbara, California, 13-18 January 1991. It provides a current assessment of the pertinent issues with respect to general microstructural and compositional design strategies, evaluation of mechanical properties, characterization of damage, failure and crack-tip shielding modes, and (potential) life-prediction procedures for metal-matrix composites, intermetallics and intermetallic-matrix composites, and ceramics and ceramic-matrix composites. In addition, there is some discussion of future trends in advanced materials, covering both the optimization of both microstructure and composite architecture. A listing of the conference participants and the technical program are appended to the report.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☑ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code); 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

TABLE OF CONTENTS

ENGINEERING FOUNDATION CONFERENCE
ON
MECHANICAL FATIGUE OF ADVANCED MATERIALS

R. O. Ritchie, R. H. Dauskardt and B. N. Cox

FOREWORD

This document constitutes the Final Report on the International Conference on Mechanical Fatigue of Advanced Materials, held under the auspices of the Engineering Foundation at the Sheraton Hotel, Santa Barbara, California, on January 13-18, 1991, with Drs. R. O. Ritchie, R. H. Dauskardt and B. N. Cox as Conference Chairmen. In addition to the Engineering Foundation, the meeting was co-sponsored by grants from the U.S. Air Force of Scientific Research, the U.S. Army Research Office, the National Science Foundation, and the U.S. Office of Naval Research.

ABSTRACT

This document provides a description and technical summary of the International Engineering Foundation Conference on Mechanical Fatigue of Advanced Materials, held in Santa Barbara, California, 13-18 January 1991. It provides a current assessment of the pertinent issues with respect to general microstructural and compositional design strategies, evaluation of mechanical properties, characterization of damage, failure and crack-tip shielding modes, and (potential) life-prediction procedures for metal-matrix composites, intermetallics and intermetallic-matrix composites, and ceramics and ceramic-matrix composites. In addition, discussion is included of future trends in advanced materials, covering both the optimization of both microstructure and composite architecture. A listing of the conference participants and the technical program are appended to the report.

INTRODUCTION

The international conference on *Mechanical Fatigue in Advanced Materials* was held at the Sheraton Hotel in Santa Barbara, California, during the week of January 13-18, 1991, under the auspices of the Engineering Foundation. The conference was organized by Dr. Brian N. Cox of the Rockwell International Science Center and Dr. Reinhold H. Dauskardt and Professor Robert O. Ritchie from the University of California at Berkeley.

Sponsorship, principally in the form of travel support for participants, and fellowships for graduate student attendees, was provided by the Air Force Office of Scientific Research, the Army Research Office, the National Science Foundation, and the Office of Naval Research, in addition to the Engineering Foundation.

The conference focused on the (cyclic) fatigue behavior of advanced materials, which included metal-matrix composites, structural ceramics and ceramic-matrix composites, and intermetallics and intermetallic-matrix composites. These materials have broad applications wherever tolerance of corrosive environments or high temperature or high specific strength, stiffness, or hardness is required, yet to date have received comparatively little attention regarding their properties under cyclic loading conditions. The conference was convened both to document and encourage fundamental investigations into the nature and micro-mechanisms by which mechanical fatigue occurs in such brittle materials, with emphasis on the ways in which their brittleness sets them apart from more traditional ductile materials, and to discuss the question of life prediction.

The participating research specialists represented three traditionally distinct groups: ceramists, who have remained until now largely oblivious of the implications of mechanical fatigue for designing and fabricating new materials; metallurgists, who are making quite brittle materials (e.g., Ti_xAl composites) while barely consulting the extensive body of understanding compiled by ceramists; and fatigue specialists, whose collective experience in the mechanical degradation of advanced low-ductility materials can be counted in a mere handful of technical papers. Indeed, the major achievement of the conference was to sow the seeds of collaboration between these groups, by bringing them together in active discussions, stimulated by key papers that repeatedly demonstrated the interdisciplinary nature of this new research area.

In all, 68 researchers participated, coming from Australia (4), England (7), France (1), Germany (2), Israel (1), Japan (4), Sweden (1) and the U.S. An attendance list is given in the appendix to this report. Also appended to the report is a copy of the technical program, which consisted of 15 invited and 19 contributed talks. The program was divided into 8 half-day sessions, each with typically 2 invited presentations and 1 contributed presentation, with remaining time devoted to discussion, and one half-day session for contributed papers. The topics of the sessions concerned fundamentals, ceramics and ceramic-matrix composites, intermetallics, metal-matrix composites and interfaces.

The technical content of the meeting was extremely good, with presentations generally of unusually high standard. In addition, there was ample time for discussion (by design), which resulted in a lively and informative meeting. Significant advances were made, both at the fundamental level, where many of the critical issues were brought sharply into focus, and with respect to practical engineering application, where the potential importance of cyclic fatigue in the use of advanced materials was demonstrated.

A summary of the technical progress reviewed at the meeting is given below, based on the closing comments of the conference chairmen. This summary, together with written versions of the majority of the presentations, is due to be published by Materials and Component Engineering Publications Ltd., of Edgbaston, U.K., under the title of *"Fatigue of Advanced Materials,"* edited by R. O. Ritchie, R. H. Dauskardt, and B. N. Cox.

CONFERENCE SUMMARY

Structural materials are rarely designed with compositions and microstructures optimized for fatigue resistance. Metallic alloys are generally designed for strength, intermetallics for ductility, and ceramics for toughness, yet if any of these materials see engineering service, their structural integrity is often limited by their mechanical performance under cyclic loads. In fact, it is currently estimated that over 80% of all service failures can be traced to cyclic fatigue, whether in association with cyclic plasticity, sliding or physical contact (fretting and rolling contact fatigue), environmental damage (corrosion fatigue), or elevated temperatures (creep fatigue). Accordingly, a large volume of literature has been amassed, particularly over the past twenty years, dealing with the mechanics and mechanisms of mechanical fatigue failure; unfortunately, however, the vast majority of this research pertains solely to metallic materials. To rectify this situation, the papers in the conference were selected to represent a definitive assessment of the current status of a relatively new field, that of the cyclic fatigue behavior of metal-matrix composites, intermetallics and their composites, and ceramics and their composites, which we refer to collectively as advanced materials.

To provide a summary, the current status of what is known about each of the three types of materials will be reviewed. This will take the form of an assessment of general microstructural and compositional design strategies and the question of whether microstructures have been optimized for fatigue resistance; an evaluation of mechanical properties with respect to cyclic constitutive behavior, crack initiation and crack-propagation data; a characterization of damage, failure and crack-tip shielding modes including the identification of phenomenological mechanisms and associated micromechanical models; a discussion of (potential) life-prediction procedures; and finally some remarks about anticipated trends in advanced materials and research into their fatigue properties. We begin, for comparison, with a brief assessment of the current status of what is known about the fatigue properties of conventional monolithic metallic alloys.

Monolithic Metals

The fatigue of metals has been a critically important engineering problem since the last century when failures of railway axles at stresses below the elastic limit were first reported in Europe. Since that time, abundant information has appeared in the literature on optimum compositions and microstructures for metallic materials, cyclic stress/strain behavior, crack initiation and crack-propagation rates, and stress-strain/life (S/N) data. Moreover, procedures for life prediction and durability are well established: for most safety-critical applications, damage-tolerant procedures are utilized involving the estimation (through integration of crack velocity/stress intensity (v/K) relationships) of the time or number of cycles for the largest undetected crack to *propagate* to failure; for other applications, S/N curves are generally utilized, where life is predicted from laboratory data relating the *total* life to the applied stress or strain after consideration has been made for such variables as mean stress, notches, surface finish, and so forth. Areas of uncertainty remain, however. The fundamental mechanisms by which fatigue cracks advance in metals are still not fully understood; moreover, specific crack-tip shielding mechanisms which act to impede crack growth, such as crack closure induced by the wedging action of fracture-surface asperities, still provoke some controversy in the literature. Finally, apart from certain specific applications such as life estimation for gas-turbine blades, the relevance of "small-crack" data is not fully appreciated.

Metal-Matrix Composites

Information on advanced materials is far more scarce. For metal-matrix composites, although considerable progress has been made with processing techniques to develop microstructures which confer desired properties, in most cases this has been achieved empirically with little scientific input or understanding of the salient micro-mechanisms. Moreover, apart from the development of aluminum-matrix laminates such as ARALL, few metallic alloy composites have been designed specifically for optimum fatigue strength.

With respect to mechanical property evaluation, there is a growing database for both discontinuously and continuously reinforced materials consisting of S/N and fatigue-crack propagation results, but comparatively little information has been published on crack-initiation properties. On the other hand, in terms of damage and failure mode characterization, several salient micro-mechanisms have been identified and modelled, such as crack trapping and uncracked ligament bridging in particulate-reinforced alloys and crack bridging in continuous fiber-reinforced alloys. However, for many potential applications, far more studies are required to understand the performance of these materials at elevated temperatures and in service environments.

Life-prediction procedures for discontinuously-reinforced metal-matrix composites can essentially mimic those for conventional metallic materials; for example, since in most cases fracture results from the growth of a single dominant crack, the fracture mechanics based damage-tolerant methodology can be directly applicable. However, in the continuously-reinforced systems, depending upon the relative strengths of reinforcement phase, matrix, and interfaces, failure can result from either the growth of a single crack or from damage distributed throughout the material. In the latter case, life-prediction becomes far more complex and may involve combined fracture mechanics and damage mechanics analyses, such as the "remaining strength" approach described by Reifsnider.

As with most new advanced materials, what is required in the future is essentially more engineering data and, most importantly, a more fundamental understanding of how damage and cracking evolve in these alloys. Of particular importance would be parametric studies on a series of controlled heats to study the specific role of primary microstructural variables, e.g., reinforcement phase size, volume fraction, morphology, matrix properties, interface strength, etc., in influencing fatigue properties. Somewhat surprisingly in metal-based composites, few studies to date have attempted to examine these factors in a systematic fashion.

Intermetallics and Intermetallic-Matrix Composites

Driven by potential application in such major projects as the U.S. National Aerospace Plane and the development of high performance turbine engines, research into the metallurgy and properties of intermetallics has mushroomed in recent years. Extensive studies have now been published on the basic microstructure of the monolithic alloys, particularly in the case of nickel and titanium aluminides, and several composite structures have been processed, including those reinforced by continuous brittle fibers (e.g., in γ-TiAl/SiC_f) or ductile particles (e.g., in γ-TiAl/Ti-Nb). Moreover, particularly in the processing of composite alloys, the design of these materials has often been supported by realistic modelling of the primary toughening mechanisms involved. However, as with metal-matrix composites, few microstructures or compositions have been optimized for maximum fatigue strength. In fact, as reported in this conference, ductile-particle toughened composites, which display significantly higher toughness than the monolithic intermetallics due to extensive crack bridging via the uncracked ductile phase, are far less effective under cyclic loading simply because the ductile metal phase fails readily by fatigue and thus cannot act as a crack bridge.

Compared to many other advanced materials, the database for the fatigue properties of intermetallic alloys and their composites is quite extensive. There is considerable information in the literature on cyclic constitutive behavior, S/N properties, and crack initiation and crack-propagation rates; however, as with metal-matrix composites, little information exists on fatigue performance at elevated temperatures or in the active environments typical of anticipated service conditions. The identification and modelling of the principal damage, failure and shielding mechanisms is also quite advanced, particularly with respect to those contributing to mechanical properties under non-cyclic loads. A prime example of this is the crack-bridging modeling developed over the past few years, for bridging both by brittle fibers and by ductile particles. In the case of bridging by aligned fibers with weak interfaces, bridging models have also succeeded in accounting accurately for the very pronounced effects of large-scale bridging for Mode I fatigue cracks growing normal to the fibers. These effects can lead, for example, to asymptotically constant propagation rates as cracks grow at constant applied load amplitude. The bridging models forge a direct link between delicate experimental measurements of the mechanical properties of interfaces around individual fibers and the growth-rate variations measured in engineering fatigue tests, allowing an accurate prediction of the effect of the shielding mechanism on fatigue-crack advance. Nevertheless, information is still lacking about fatigue failure in the same fibrous composites by other mechanisms such as splitting along the fiber direction, which may well be the prevalent mode of failure, depending on the load configuration and specimen geometry.

It is anticipated that life-prediction procedures for intermetallic materials would largely be similar to those outlined for metal-matrix composites, i.e., relying on conventional S/N or damage-tolerant analyses for most monolithic materials, with an option of damage mechanics methodologies for more complex composite structures where the damage may be more distributed. The exception to this may well be for composites toughened by extensive crack bridging, where although failure may result from a single dominant flaw, the bridging would induce strong geometry effects. Moreover, since intermetallics can sometimes behave more like ceramics, as with γ-TiAl, rather than metals, as with α-Ti_3Al, additional problems associated with these approaches, as outlined below for ceramics, may well be pertinent.

With respect to future needs, clearly far more engineering data are required, together with an accompanying mechanistic understanding, both for variable-amplitude loading spectra as well as simple constant-amplitude spectra. Moreover, as repeated above, if these materials are ever to be used in earnest, it is essential that a thorough understanding should be available of their properties in the elevated-temperature environmental conditions that they may experience in service. To date, such information is sadly lacking.

Ceramics and Ceramic-Matrix Composites

The development of toughened ceramics over the past ten to fifteen years is arguably one of the most important material design breakthroughs of this century. Using technologies based on scientific understanding and models for *in situ* phase transformation, fiber bridging, ductile-particle toughening and so forth, monolithic and composite ceramic materials have been processed with fracture toughnesses in many cases up to an order of magnitude higher than those available twenty years ago. The irony of this, however, is that although ceramics can now be considered seriously for many potential structural applications, they can, contrary to popular belief, be susceptible to degradation under cyclic fatigue loading. In view of the importance of cyclic loading in many of these applications, such as in gas-turbine and reciprocating engines, the topic of "ceramic fatigue" has attracted much recent attention. However, since the field is still in its infancy, documentation of fatigue properties is very limited.

understanding of salient mechanisms has not been achieved, and the design of microstructures for optimum fatigue resistance has yet to be attempted.

Although mechanical property data for the fatigue of ceramics are still extremely limited, there are a few studies on the cyclic constitutive behavior of phase-transforming ceramics and, especially in the Japanese literature, S/N data for most monolithic ceramics tested by a variety of techniques, e.g., push-pull, tension-compression, three-point bending, rotating bending, etc. Corresponding results for ceramic-matrix composites, however, are much rarer. Also, a few laboratories in the U.S., Europe and Japan are generating fatigue-crack propagation (v/K) results for many monolithic and composite ceramic systems, and traditional fatigue variables such as mean stress, variable-amplitude loading, environment, etc., have started to be examined. These results have shown that in many ceramics the fatigue effect can be very significant; for example, fatigue thresholds are generally found to be as low as 50% of the fracture toughness K_{Ic}, and the velocities of cyclic fatigue cracks can exceed those under sustained (static-fatigue) loading at the same stress intensity by many orders of magnitude. However, despite this rapidly expanding database, few if any studies have been directed to crack-initiation phenomena; moreover, there are only one or two limited studies of ceramic fatigue in the vitally important high-temperature regime and none that considers the role of the environment at these temperatures.

There is similarly a paucity of knowledge with respect to the characterization of damage and failure modes for ceramic fatigue. For example, the basic mechanisms of cyclic crack growth in ceramics are still very uncertain. Essentially, there are two possible classes of mechanisms where failure is associated with a dominant crack (in many materials both types may well operate in concert): namely, *intrinsic mechanisms* where, as in metals, crack advance results from damage processes in the crack-tip region which are unique to cyclic loading (just as striation growth under cyclic loads is distinct from microvoid coalescence or cleavage under monotonic loading in metals); and *extrinsic mechanisms*, where the crack-advance mechanism is identical to that for monotonic loading but the unloading cycle promotes accelerated crack growth by degrading the degree of crack tip shielding. Limited examples of both types of processes have been suggested, such as the enhanced microcracking zones ahead of fatigue cracks in whisker-reinforced Al_2O_3/SiC composites at high temperatures (intrinsic), and the wearing away of interlocking grain bridges in fatigue cracks in monolithic coarse-grained alumina at ambient temperatures (extrinsic). Clearly, much more research is required to discriminate these mechanisms and to model them quantitatively before realistic guidelines can be presented for designing ceramic microstructures with improved fatigue resistance.

A major problem with ceramics and their composites is the question of life prediction. Because the measured slopes (exponents) of v/K data and the reciprocal slopes of S/N curves are so high (exponents of 20 and above are common for fatigue behavior in certain ceramics), the sensitivity of the projected life to the applied stress can be unacceptably high. For example, for a ceramic with a v/K exponent of 50, a factor of 2 change in the applied stress results in a decrease in the projected lifetime of over 15 orders of magnitude! A possible solution to this problem could be to design on the basis of the fatigue-crack propagation threshold, below which cracks are presumed dormant; as noted above, measured thresholds in ceramic fatigue are typically ~50% of K_{Ic}. However, as reported in this conference, "small" fatigue cracks have been shown to grow in ceramics at rates far in excess of equivalent long cracks and at nominal stress intensities far below this threshold, making this approach highly non-conservative. "Small" in this context is defined relative to the size of the equilibrium shielding zone (e.g., comparable in size to the extent of crack bridging in the wake of the crack tip); in fact, the primary reason for this seemingly anomalous behavior is that small cracks, by virtue of their limited wake, are unable to develop the same extent of crack-tip shielding. (This effect is identical to the small-crack effect widely reported in metals, where crack closure provides the dominant shielding). With detailed knowledge and quantitative modelling of the shielding mechanism, it is possible to normalize long and small crack data by characterizing in terms of the *near-tip* or net stress intensity (i.e., after subtracting out the stress intensity due to shielding); however, whether this is practicable on a regular engineering basis for all ceramic materials in service in the field is clearly questionable.

Of all the advanced materials discussed in this conference, ceramics and their composites require the most work in the future with respect to fatigue behavior. The relevance of the cyclic properties of ceramics to potential applications is obvious, yet currently, besides the uncertainty in life-prediction methodologies noted above, there are only limited engineering S/N and v/K data, little fundamental understanding of damage and failure modes or crack-advance mechanisms, and virtually no knowledge of what constitutes a fatigue-resistant microstructure or composition. Clearly, much future effort must be devoted to this topic, particularly utilizing elevated temperature and environmental conditions, if ceramic materials are ever to realize their promised future applications.

Future Trends in Advanced Materials

Optimizing Microstructure: An increased understanding of the detailed micromechanisms of fatigue degradation in advanced materials, together with more precise specification of material property requirements, will ultimately allow modification of composite microstructures to provide an optimal combination of desired properties. This approach, however, will inevitably lead to compromise between different sets of properties. Trade-offs have already been observed between strength and toughness in transformation-toughened and second-phase reinforced ceramics. Indeed, the microstructural design of metallic alloys has a well established legacy of such property compromises. In steels, for example, high strength is known to favor increased resistance to fatigue-crack initiation but can be deleterious to crack growth; similarly, microstructural features may produce inverse effects on toughness and subcritical crack growth. Clearly, the ultimate goal in the design of microstructures in advanced materials must be to achieve an optimum set of mechanical properties which are tailored to the in-service requirements.

Optimizing Composite Architecture: Another important area of research for advanced materials pertains to the problem of weakness under non-axial loading and its ramifications for design, fabrication and reliability. Some of the most acclaimed high-temperature materials are intermetallic and ceramic composites reinforced by continuous fibers. Great success has been achieved in providing these materials with high strength, toughness, and fatigue resistance for loading in the axial direction by controlling the properties of the fiber/matrix interface. However, while focusing on axial properties was justifiable in the early days of their development, it must now be recognized that the outstanding weakness of these materials is under non-axial loading. The very weakness of the interfaces that is so advantageous for axial properties makes the composite unusually vulnerable to delamination under shear or impact loading or tensile failure under transverse loading.

There are interesting parallels between this situation and the history of development of polymer composites for critical applications requiring damage tolerance. With the development of strong fibers and tougher resins, axial strength in polymer composites is now often taken for granted. Yet polymer composites have not yet found wide use in commercial airframes, for example, because they are vulnerable to delamination, especially following impact damage. The quest for a solution to this problem in polymer composites has led naturally to the development of multidimensional reinforcement, i.e., braided, knitted, woven, and stitched fiber preforms, where a significant volume fraction of fibers carries load not only in both in-plane directions but also in the through-thickness direction.

Early results for such three-dimensional polymer composites are very encouraging. At the price of some degradation of axial properties, substantial improvements are obtained in transverse and shear strength and residual strength after impact. It is now very likely that the same reinforcement architectures will begin to appear in intermetallic and ceramic composites at large. Along with their arrival we can anticipate a completely new set of fatigue problems. Again referring to the analog offered by polymer composites, we must expect that the mechanics of failure of brittle 3-D composites will be qualitatively different from those of the unidirectional materials studied to date. In place of a single dominant crack or a few cracks growing normal to the fibers, there may appear complex distributed damage involving highly inhomogeneous local stress fields and the interactions of many microcracks, failed fibers, and at high temperatures, plasticity. Cataloging and modelling such new and different modes of failure promises to be a thriving area of fatigue research for many years to come.

APPENDIX

1. List of Conference Participants
2. Technical Program

Engineering Foundation Conferences

Mechanical Fatigue in Advanced Materials

Sheraton Santa Barbara Hotel & Spa
Santa Barbara
January 13 to January 18, 1991

PARTICIPANT'S LIST

Allen, Clive B., Principal Engineer
Rolls Royce Plc

Allison, John E., Staff Scientist
Ford Motor Company

Andersson, Clarence A., Material Scientist
Lanxide Corporation

Argon, Ali S., Professor
Massachusetts Institute of Technology

Bao, Gang, Assistant Research Engineer
University of California at Santa Barbara

Bar-On, Isa, Associate Professor
Worcester Polytechnic Institute

Becher, Paul F., Group Leader
Oak Ridge National Laboratory

Beevers, Christopher J., Senior Lecturer
University of Birmingham

Bowen, Paul, Lecturer
University of Birmingham

Brook, Richard, Director
Max Planck Institute

Cannon, Rowland M., Staff Scientist
Lawrence Berkeley Laboratory

Carlsson, Lennart F. A., Associate Professor
Swedish National Test Inst.

Chan, Kwai S., Principal Engineer
Southwest Research Institute

Chen, I-Wei, Professor
University of Michigan

Cox, Brian N., Member of Technical Staff
Rockwell International Science Center

Dadkhah, Mahyar S., Member of Technical Staff
Rockwell International Science Center

Dauskardt, Reiner H., Staff Scientist
Lawrence Berkeley Laboratory
University of California at Berkeley

Davidson, David L., Institute Scientist
Southwest Research Institute

Deve, Herve E., Research Engineer
University of California at Santa Barbara

Donaldson, Jack V.
Engineering Foundation

Downes, Terry, Research Student
Cambridge University

Elyada, Dov.
Rafael (Israel)

Evans, Anthony G., Professor
University of California at Santa Barbara

Fishman, Steven G., Program Manager
Office of Naval Research

Giamei, Anthony F., Principal Scientist
United Tech. Research Center

Guiu, Frank, Reader
Queen Mary & Westfield

Heness, Greg L., Ph.D. Student
University of Technology

Hoffman, Mark J., Ph.D. Student
University of Sydney

Hutchinson, John A., Professor
Harvard University

James, Michael R., Manager, Mechanics of Mat.
Rockwell International Science Center

Johnson, W. S., Senior Scientist
NASA Langley Research Center

Kinloch, Anthony J., Professor
Imperial College

Kishimoto, Hidehiro, Professor
Toyota Technological Institute

Lamon, Jacques Luc, Research Director
Lab. des Composites

Lindley, Trevor C., Research Officer
National Power UK

Liu, Chang-Qi, Associate Professor
Case Western Reserve

Liu, Tianshun
Institut fur Werkstoffkunde

Liu, Jimmy, Project Manager
Phillips Lab.

Lo, Calvin S., Graduate Student
University of California at Santa Barbara

Marshall, David B., Manager, Structural Ceramic
Rockwell International Science Center

McEvily, Arthur J., Professor
University of Connecticut

Morris, Winfred L., Member of Technical Staff
Rockwell International Science Center

Mutoh, Yoshiharu, Professor
Nagaoka University of Tech.

Nicholas, Theodore, Senior Scientist
AFWAL/MLLN

Odette, G. R., Professor
University of California at Santa Barbara

Ohya, Kanji, General Manager
NGK Spark Plug Co., Ltd.

Ota, Mark
NGK Spark Plug Co., Inc.

Pelloux, Regis M., Professor
Massachusetts Institute of Technology

Reifsnider, Ken I., Professor
Virginia Polytech. Institute

Ritchie, Robert O., Professor
University of California at Berkeley

Rhodes, Cecil, Member of Technical Staff
Rockwell International Science Center

Roedel, Juergen W., Research Associate
National Institute of Standard

Rose, Francis
Aeronautical Research Lab.

Rosenstein, Alan H., Deputy Director - Materials
Air Force Office of Scientific Research

Russell, Dale, Member of Technical Staff
Rockwell International

Santy, Myrrl J., Mgr. Matls Engrg. & Tech.
TRW

Schoutens, Jacques
Kaman Sciences Corp., S.B.

Spearing, Simon M., Assistant Research Engineer
University of California at Santa Barbara

Stoloff, Norman S., Professor
Rensselaer Polytech. Institute

Suresh, Subra, Professor
Brown University

Swain, Michael, Professor
University of Sydney

Van Stone, Robert H., Senior Engineer
GE Aircraft Engines

Venkateswara Rao, K. T., Post-Doctoral Fellow
University of California at Berkeley
Lawrence Berkeley Laboratory

Walls, David P., Graduate Student
University of California at Santa Barbara

Wiederhorn, Sheldon
National Institute of Standards & Technology

Williams, Katherine A., Materials Research Engrg.
U.S. Air Force

Xu, Junde, Graduate Student
University of California at Santa Barbara

Ye, Tao
University of California at Santa Barbara

Zok, Frank W., Assistant Professor
University of California at Santa Barbara

Engineering Foundation Conference

on

"MECHANICAL FATIGUE OF ADVANCED MATERIALS"

January 13-18, 1991

Santa Barbara California

Co-chairmen: B.N. Cox, R.H. Dauskardt, and R.O. Ritchie

Final Schedule of Sessions

Sunday, January 13, 1991

3:00 p.m. - 9:00 p.m.	REGISTRATION AND CHECK-IN
6:00 p.m.	DINNER
9:00 p.m. - 11:00 p.m.	SOCIAL HOUR

Monday, January 14, 1991

9:00 a.m. - 12:30 p.m.	OPENING SESSION *"Opening Remarks"* R.O. Ritchie **GENERAL SESSION ON FUNDAMENTALS I** Chairman: B.N. Cox *"Crack Resistance in Advanced Materials"* A.G. Evans (invited) *"Mechanics of Interfaces"* J.W. Hutchinson (invited) *"Reduction of the Shielding Term During Cyclic Fatigue in Alumina"* "J. Rödel, S. Lathabai, and B.R. Lawn (contributed)
12:30 p.m.	LUNCH
2:00 p.m. - 5:00 p.m.	AD HOC SESSION
5:00 p.m.	SOCIAL HOUR
6:00 p.m.	DINNER
7:30 p.m. - 10:00 p.m.	**GENERAL SESSION ON FUNDAMENTALS II** Chairman: R.H. Dauskardt *"Advanced Ceramics"* R. Brook (invited) *"Cyclic Fatigue"* D.L. Davidson (invited)

Invited papers will be of 45 mins. duration; contributed papers 15 mins.

	"Cyclic Fatigue in Some Structural Ceramics" F. Guiu, M.J. Reece, and D.A.J. Vaughan (contributed)
10:00 p.m.	SOCIAL HOUR
Tuesday, January 15, 1991	
7:30 a.m.	BREAKFAST
9:00 - 12:30 p.m.	**CERAMICS/CERAMIC COMPOSITES I** Chairman: D.B. Marshall
	"Cyclic Fatigue Crack Growth in Ceramics" R.H. Dauskardt and R.O. Ritchie (invited)
	"Small Crack Behavior in Ceramics: Direct Observations and Inferences from Strength Data" M.V. Swain (invited)
	"Static and Cyclic Fatigue of the Transformation Toughened Y-TZP(A) and Ce-TZP Ceramics" T. Liu and G. Grathwohl (contributed)
12:30 p.m.	LUNCH
2:00 p.m. - 5:00 p.m.	AD HOC SESSION
5:00 p.m.	SOCIAL HOUR
6:00 p.m.	DINNER
7:30 p.m. - 10:00 p.m.	**CERAMICS/CERAMIC COMPOSITES II** Chairman: P. Becher
	"High-Temperature Fatigue of Ceramics" S. Suresh (invited)
	"Low Cycle Fatigue and Constitutive Laws" I.W. Chen (invited)
	"Crack Growth in Silicon Nitride Under Cyclic Loading" M. Okazaki, A.J. McEvily, and T. Tanaka (contributed)
10:00 p.m.	SOCIAL HOUR
Wednesday, January 16, 1991	
7:30 a.m.	BREAKFAST
9:00 a.m. - 12:30 p.m.	**INTERMETALLICS I** Chairman: T. Nicholas
	"Initiation and Growth in Intermetallic Compounds" N.S. Stoloff (invited)
	"Fatigue of Titanium Aluminides at Ambient and Elevated Temperatures" P. Bowen (contributed)
	"On the Contrasting Role of a Ductile Phase Reinforcement in the Fracture Toughness and Cyclic Fatigue Crack Growth Properties of γTiAl" K.T. Venkateswara Rao and R.O. Ritchie (contributed)

Invited papers will be of 45 mins. duration; contributed papers 15 mins.

"Effects of Matrix Microstructure and Particle Reinforcement on the Bauschinger Effect and Low Cycle Fatigue Behavior of Aluminum Matrix Composites"
C. Liu, C.A. Hippsley, and J.L. Lewandowski (contributed)

"Fiber Sliding in Brittle Composites"
D.B. Marshall (contributed)

12:30 NOON — LUNCH

2:00 p.m. - 5:00 p.m. — AD HOC SESSION

5:00 p.m. — SOCIAL HOUR

6:00 p.m. — DINNER

7:30 p.m. - 10:00 p.m. — **INTERMETALLICS II**
Chairman: A.F. Giamei

"Fatigue and Fracture of Brittle Fibrous Composites"
B.N. Cox (invited)

"Subcritical Cracking in Ti_xAl + Nb"
G.R. Odette (invited)

"Fatigue Crack Growth in a Ti/SiC Composite"
D. Walls, G. Bao, and F. Zok (contributed)

10:00 p.m. — SOCIAL HOUR

Thursday, January 17, 1991

7:30 a.m. — BREAKFAST

9:00 a.m. - 12:30 p.m. — **METAL-MATRIX COMPOSITES**
Chairman: K.S. Chan

"Fatigue of Continuous-Fiber Composites"
W.S. Johnson (invited)

"Life Prediction in Advanced Materials Systems"
K.L. Reifsnider (invited)

"Fatigue Crack Growth in Al Matrix-SiC Fibre Composites"
R.J. Mustafa and F. Guiu

12:30 p.m. — LUNCH

2:00 p.m. - 5:00 p.m. — AD HOC SESSION

5:00 p.m. — SOCIAL HOUR

6:00 p.m. — DINNER

7:30 p.m. - 10:00 p.m. — **SESSION OF CONTRIBUTED PAPERS**
Chairman: R.H. Dauskardt

"Fatigue of Zirconia-Ceria at Ambient Temperatures"
C.J. Beevers and D. Cardona

Invited papers will be of 45 mins. duration; contributed papers 15 mins.

"Fatigue Crack Growth of Long and Short Cracks in Silicon Nitride"
Y. Mutoh and M. Takahashi

"Cyclic Fatigue Properties of Sintered Si_3N_4"
K. Ohya, M. Takatsu, and K. Ogura

"Crack Propagation of Sintered Silicon Nitride Under Cyclic Load"
H. Kishimoto

"Cyclic Fatigue Crack Propagation in SiC_W Reinforced Alumina"
I. Bar-On and R.N. Katz

"Particle Size Effects on Short and Long Fatigue Crack Growth in an Aluminum Silicon Carbide Composite"
T.J. Downes, D.M. Knowles, and J.E. King

"Creep of Ceramics"
Shelley Wiederhorn

"Probabilistic Fracture Analysis of Unidirectional Long-Fiber Composites"
J. Lamon

10:00 p.m. SOCIAL HOUR

Friday, January 18, 1991

7:30 a.m. BREAKFAST

9:00 a.m. - 12:30 p.m. **INTERFACES**
Chairman, A.S. Argon

"Ceramic-Metal Interfaces"
R.M. Cannon (invited)

"Polymer-Metal Interfaces"
A.J. Kinloch (invited)

"Fatigue Crack Growth in Fiber-Reinforced Metal-Matrix Composites"
K.S. Chan and D.L. Davidson (contributed)

SUMMARY AND CLOSING SESSION
Chair: B.N. Cox

"Conference Summary"
R.O. Ritchie

12:30 p.m. LUNCH

ADJOURNMENT

Invited papers will be of 45 mins. duration; contributed papers 15 mins.