

2006 ASM/TMS SPRING SYMPOSIUM

MULTI-PHASE AND COMPOSITE MATERIALS

PROGRAM AND ABSTRACTS

May 22nd & 23rd, 2006

**GE Global Research
Niskayuna, NY**

MULTI-PHASE AND COMPOSITE MATERIALS

May 22nd & 23rd, 2006

GE Global Research
Niskayuna, NY

OBJECTIVES

Co-sponsored by the Eastern New York Chapter of ASM and the Hudson-Mohawk Chapter of TMS, a Technical Symposium on a topic of materials science and engineering is held annually in the spring. The purposes of the technical symposium are to provide opportunities for technical information exchange between professionals, to provide continuing education for professionals, and to educate students in science and engineering fields in Eastern New York.

2006 Spring Symposium Organizing Committee

Timothy Hanlon (GEGR), Symposium Committee Chair

Matt Alinger (GEGR)	Frank Johnson (GEGR)
Bernard Bewlay (GEGR)	Dana Levene (KAPL)
Laurent Cretegny (GEGR)	Daniel Lewis (RPI)
Voramom Dheeradhada (GEGR)	Judson Marte (GEGR)
Lisa D'Amore (KAPL)	Michelle Othon (GEGR)
Richard DiDomizio (GEGR)	Louis Peluso (GEGR)
Kathy Dunn (SUNY, Albany)	Linda Schadler (RPI)
William Heward (GEGR)	Jonathan Schneider (KAPL)
Luana Iorio (GEGR)	Seth Taylor (GEGR)
Liang Jiang (GEGR)	

2006 ASM/TMS Spring Symposium ***Multi-Phase and Composite Materials***

GE Global Research, Niskayuna, NY

Monday, May 22nd, 2006

- 7:30 - 8:30 Check-in/registration and coffee
8:30 - 8:45 Opening Remarks: Mark Little, Senior Vice President
GE Global Research

Session I *In Situ Composite Processing*

Chairs: Judson Marte & Voramon Dheeradhada, GE Global Research

- 8:45 - 9:30 Stephen Kampe (Virginia Polytechnic Institute and State University) – *An Overview of In Situ Metal Matrix Composites*
9:30 - 10:15 David Johnson (Purdue University) – *Solidification Processing and Mechanical Properties of RuAl-based Alloys*
10:15 - 10:30 *Break*
10:30 - 11:15 Vinod Sikka (Oak Ridge National Laboratory) – *Development and Applications of Ni₃Al-based Intermetallics*
11:15 - 12:00 Wendy Lin (GE Global Research) – *Composite Wind Blade Materials & Processing – Pros & Cons*
12:00 - 1:00 *Lunch*

Session II *Engineered Composite Processing*

Chairs: Richard DiDomizio, GE Global Research
Jonathan Schneider, KAPL, Inc.

- 1:15 - 2:00 Suresh Advani (University of Delaware) – *Use of Flow Simulation for Design, Optimization and Control of Liquid Composite Molding Processes*
2:00 - 2:45 Gregory Corman (GE Global Research) – *Melt Infiltrated Ceramic Composites for Gas Turbine Applications*
2:45 - 3:00 *Break*
3:00 - 3:45 Dean Poeth (The Graduate College of Union University) – *A Method for Evaluating Manufacturing Damage in Monolithic and Composite Materials*
3:45 - 4:30 Yozo Mikata (Lockheed Martin – KAPL, Inc.) – *Effective Thermal Conductivity of Fiber Reinforced Composites by Eshelby's Method*
4:45 - 5:30 **Tour of GE Global Research**

2006 ASM/TMS Spring Symposium ***Multi-Phase and Composite Materials***

GE Global Research, Niskayuna, NY

Monday evening, May 22nd, 2006

6:00 - 7:00 Hors d'oeuvres and Cash Bar Reception (Glen Sanders Mansion)

7:00 - 8:00 Symposium Dinner

8:00 - 9:00 Dinner Talk: Stephen Sass (Cornell University)

*The Substance of Civilization: Materials and Human History from
the Stone Age to the Age of Silicon*

Abstract

Materials have enabled revolutionary advances in how we live, work, fight and travel, hence the naming of eras after them -- Stone, Bronze and Iron Ages. This talk explores the role of materials in the development of modern Western industrial civilizations, by putting technology into an historical and human context, examining the advances made possible by innovations with materials, starting with the Stone Age. Connections between critical developments are identified, for example, the relationship among materials, agriculture and written languages in the fourth millennium B.C., and among the Exodus of the Hebrews, the general tumult in the Eastern Mediterranean and the onset of the Iron Age, at the end of the second millennium B.C. The roles of China and Islam in stimulating advances in technology will be explored. Early technologies will be illustrated with beautiful works of art.

A biographical sketch of Stephen Sass can be found on page 13.

Directions to Glen Sanders Mansion:

- Turn right out of the GE Global Research Center onto the traffic circle
- Take first right off traffic circle onto River Rd.
- Follow River Rd. through light at Balltown Rd (River Rd. becomes Rosa Rd. at this light)
- Follow Rosa Rd. to Nott St. (Ellis Hospital will be on your left), take a right onto Nott St.
- Follow Nott St. to Erie Blvd., take left onto Erie Blvd.
- Travel into downtown Schenectady (~0.6 mile) and turn right at State St. (Rt. 5)
- Take State St. (~ 1 mile) over the Mohawk River on the Western Gateway Bridge
- Turn left at the first light just over the bridge onto Glen Ave.
- The Glen Sanders Mansion is the first building on the left.

2006 ASM/TMS Spring Symposium
Multi-Phase and Composite Materials

GE Global Research, Niskayuna, NY

Tuesday, May 23rd, 2006

7:30 - 8:30 *Check-in and coffee*

Session III **Interface Engineering**

Chair: Seth Taylor, GE Global Research

8:30 - 9:10 Christopher Schuh (Massachusetts Institute of Technology) – *Grain Boundary Engineering: Composite Modeling of Grain Boundary Networks*

9:10 - 9:50 Elizabeth Dickey (Pennsylvania State University) – *Effect of Local Oxygen Activity on Metal-Ceramic Interface Chemistry*

9:50 - 10:00 *Break*

10:00 - 10:40 Brian Sheldon (Brown University) – *Toughening Mechanisms in Ceramic Composites Reinforced with Nanotubes and Nanofibers*

10:40 - 11:20 James Howe (University of Virginia) – *New Techniques for Determining the Properties of Materials and Interfaces during In Situ Heating in the TEM*

11:20 - 12:00 William Egelhoff (National Institute of Standards and Technology) – *Controlling Interfacial Structure in the Growth of Magnetic Thin Films*

12:00 - 1:00 *Lunch*

Session IV **Materials by Design**

Chairs: Frank Johnson & Bernard Bewlay, GE Global Research

1:15 - 2:00 John Lewandowski (Case-Western Reserve University) – *Flow, Fracture, and Fatigue Studies on Composites and Bulk Metallic Glasses*

2:00 - 2:45 Joseph Lemsky (Ladish Co., Inc.) – *Dual Microstructure Heat Treatment for Advanced Turbine Engine Components*

2:45 - 3:00 *Break*

3:00 - 3:45 Walter Sherwood (Starfire Systems, Inc.) – *The Development and Commercialization of Polymer Derived Ceramic Matrix Composites*

3:45 - 4:30 Charles Sullivan (Dartmouth College) – *Thin-Film Nano-Composite Soft Magnetic Materials for High Frequency Applications*

4:30 – 4:45 *Concluding Remarks*

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PROGRAM AND ABSTRACTS

May 22nd & 23rd, 2006

**GE Global Research
Niskayuna, NY**

***In Situ* Composite Processing**

Session I

Chairs: Judson Marte & Voramon Dheeradhada, GE Global Research

Authors and Titles

Stephen Kampe (Virginia Polytechnic Institute and State University)
An Overview of *In Situ* Metal Matrix Composites

David Johnson (Purdue University)
Solidification Processing and Mechanical Properties of RuAl-based Alloys

Vinod Sikka (Oak Ridge National Laboratory)
Development and Applications of Ni₃Al-based Intermetallics

Wendy Lin (GE Global Research)
Composite Wind Blade Materials and Processing – Pros and Cons

An Overview of *In Situ* Metal Matrix Composites

Stephen Kampe
Virginia Polytechnic Institute and State University
Materials Science and Engineering Department
Blacksburg, VA 24061
kampe@vt.edu

Abstract

In situ metal matrix composites offer considerable potential to contribute to ambient and high temperature alloy design, due in part to the broad microstructural flexibility and property mixes that they afford, and the inherent thermodynamic stability of the resulting microstructures and their components. Several methods of *in situ* processing have been developed; in general, these can be broadly categorized as being either reactive- or morphologically-motivated in their ability to yield effective composite microstructures. Within this context and categorization scheme, several examples of *in situ* composite processes will be introduced and reviewed. The benefits of *in situ* processing will be illustrated by results obtained from composites processed by the relatively versatile solvent mediated reaction synthesis (SMRS) technique. SMRS relies on the use of a metallic solvent to facilitate a sustained, exothermic reaction to create a dispersed reinforcing phase within a metal or intermetallic matrix. The mechanistic aspects of reaction synthesis will be discussed, especially as it influences the resulting composite microstructure and the mechanisms of composite strengthening. Several composites produced using TiB₂ reinforcement within the near- γ (TiAl+Ti₃Al) or Al₃Ti titanium aluminide matrices will be presented to illustrate the microstructural flexibility and property benefits attributable to this alloy design strategy.

Biographical Sketch

Dr. Stephen L. Kampe is Professor of Materials Science and Engineering at Virginia Polytechnic Institute and State University (Virginia Tech). He conducts research in the area of processing/structure/property relationships in metals, intermetallics, composite materials, and ceramics. Current or recent activities involve the reaction synthesis processing of multifunctional composites, characterization and modeling of laser additive manufacturing processes, mechanical behavior characterization of advanced materials, and deformation processing of metals and composites. Prior to his appointment at Virginia Tech, he was affiliated with Martin Marietta Laboratories, participating prominently in the development of the XD® family of metal and intermetallic alloys composites. Dr. Kampe has over 80 technical publications dealing with his research and materials development activities, holds seven patents in various aspects of innovative composite synthesis, and actively consults with industry towards solving a wide variety of materials related problems. He is a member of The Materials Society (TMS) of AIME, ASM International, the Materials Research Society (MRS), and the American Powder Metallurgy Institute (APMI). Dr. Kampe holds three degrees (B.S., M.S., and Ph.D) in Metallurgical Engineering from Michigan Technological University.

Solidification Processing and Mechanical Properties of RuAl-based Alloys

D. R. Johnson and T. D. Reynolds
Purdue University
School of Materials Engineering
501 Northwestern Ave.
West Lafayette, IN 47907

Abstract

Alloys of ruthenium aluminide are candidate materials for high temperature structural applications. Due to the difficulty in processing RuAl from the melt, alloys from the RuAl-Mo and the RuAl-Ru(Mo) eutectic systems were initially examined. While the RuAl-Mo alloys were found to be brittle, good room temperature fracture toughness values were found for the RuAl-Ru(Mo) alloys with values ranging from 23 to 38 MPa \sqrt{m} . For these alloys, increasing the volume fraction of RuAl resulted in a decrease in fracture toughness, and the fracture toughness of the B2 solid solution (RuAl) was found to be less than 13 MPa \sqrt{m} . For improved oxidation resistance, the development of Ru-Al-Cr alloys was pursued in which single phase Ru(Cr,Al) and two phase hcp/B2 alloys were produced by directional solidification. These alloys were found to have a good combination of properties that include a Ru content similar to RuAl, excellent oxidation resistance at 1100°C, good room temperature tensile ductility (12%) and good fracture toughness.

Biographical Sketch

David Johnson joined the faculty at Purdue University in 1998. Before that he spent four years at Kyoto University, Japan, as a research associate in the Department of Materials Science and Engineering. During this time he worked on directional solidification of TiAl-base alloys. Prior to the work in Kyoto, David received his Ph.D. from the University of Tennessee where he worked on developing NiAl-based alloys, *in situ* composites, and processing techniques to grow high purity single crystals.

Development and Applications of Ni₃Al-based Intermetallics

Vinod K. Sikka
Oak Ridge National Laboratory
Materials Science & Technology Division
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(865) 574-5112
sikkavk@ornl.gov

Abstract

This presentation will discuss the development steps for the commercialization of Ni₃Al-based materials. The development steps will address topics such as alloy composition optimization, melting process development, weld process and filler-wire development, mechanical properties, component fabrication, and industrial operating experience. The steps used in the commercialization of Ni₃Al-based materials will also be discussed.

Biographical Sketch

Dr. Vinod K. Sikka has been at the Oak Ridge National Laboratory (ORNL) for 32 years and is the manager for Research & Technology Development in the Materials Sciences & Technology Division. He received his Ph.D. from the University of Cincinnati in 1973 in the area of materials science. Dr. Sikka carries out research at ORNL in the areas related to: (1) developing new research technology development and funding opportunities, (2) developing advanced materials for structural applications, (3) developing novel methods for processing of materials, (4) developing new processing equipment, and (5) transfer of technology developed from the research to industry. His current research areas include: (1) Development and commercialization of a Fe-3Cr-W(Mo) steel for chemical industries and power plants. The alloy being developed has the highest creep strength in its class of alloys with excellent toughness at low temperatures and ease of welding. (2) Extending the upper use temperature of cast austenitic stainless steels for furnace and chemical process applications. Some of the new compositions can operate at 50 to 100°F higher temperature than the currently used alloys in this class. (3) Development of coking- and carburization-resistant alloys for ethylene production. (4) Advanced materials for steel galvanizing bath hardware. (5) Advanced materials for basic open furnace (BOF) and electric arc furnace (EAF) hoods. (6) Hydrogen storage materials based on large area/thin film concept. (7) Wireless sensors to select impacts on energy storage infrastructure. He has over 200 publications in journals and conference proceedings and 40 patents. Dr. Sikka has won several awards including seven R&D 100 Awards, a U.T.-Battelle Distinguished Inventor Award, and a Federal Laboratory Consortium Award for Excellence in Technology Transfer for "Polymer Boot Heater to Improve Vehicle Assembly-Line Ergonomics and Production."

*Research at the Oak Ridge National Laboratory was sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

Materials and Processing of Large Wind Blade Composites – Pros and Cons

Wendy Lin
GE Global Research

Abstract

Large composite wind blades are currently fabricated using a variety of processes and materials. The processes range from wet lay-up to vacuum assisted infusion to pre-preg, and the resins and adhesives range from polyesters to vinylesters to epoxies. This paper presents the relative merits and drawbacks of each of these materials and processes and some of the challenges specific to fabricating a large wind blade which needs to meet high performance requirements and still meet the cost challenge of providing 3-5 cents/kwh.

Biographical Sketch

Wendy Lin leads the Composite Team in the Polymer & Chemicals Technologies at GE Global Research in Niskayuna, NY. She joined GE in 1995 and has worked in the area of polymer matrix composites and adhesion to support new product development for GE Aviation, GE Steam Turbines, and GE Wind Energy. She also worked for the Naval Air Development Center from 1985 to 1988 on EMI composites and sealants. Dr. Lin obtained her PhD in Material Science & Engineering from Stanford University in 1993 with a thesis on induction bonding of thermoplastic carbon fiber composites. She currently has 14 patents.

Engineered Composite Processing

Session II

Chairs: Richard DiDomizio, GEGR & Jonathan Schneider, KAPL, Inc.

Authors and Titles

Suresh Advani (University of Delaware)

Use of Flow Simulation for Design Optimization and Control of Liquid Composites Molding Processes

Gregory Corman (GE Global Research)

Melt Infiltrated Ceramic Composites for Gas Turbine Applications

Dean Poeth (The Graduate College of Union University)

A Method for Evaluating Manufacturing Damage in Monolithic and Composite Materials

Yozo Mikata (Lockheed Martin – KAPL, Inc.)

Effective Thermal Conductivity of Composites by Eshelby's Method

Use of Flow Simulation for Design, Optimization and Control of Liquid Composite Molding Processes

Suresh Advani

George W. Laird Professor of Mechanical Engineering
Associate Director of Center for Composite Materials
University of Delaware
Newark, DE 19716

Abstract

Liquid Molding encompasses a family of composite manufacturing processes in which the preform is placed in a mold and low viscosity resin is infused to cover the fibers and all the empty spaces between the fibers. Over the last decade we have developed a finite element /control volume based simulation that can address the flow of resin in these processes. It accounts for the dual scale nature of the fabric and can accommodate for presence of flow enhancement channels and distribution media in the simulation system. Such science based flow simulations are being routinely used before a new prototype is designed and the prototype manufacturing process is established. As the complexity of composite structure increases, the yield from a production process decreases. This outcome stems from the variability associated with the fiber preform resistance to resin flow around the walls of the molds or inserts that are placed in the mold as the resin tries to impregnate the empty spaces between the fiber preforms in the mold. This resistance is not repeatable as it depends on how the preform is cut and placed inside a mold. This presentation will show how simulations can be extended to improve the yield by introducing optimization and control strategies to successfully fill a mold without voids. We introduce a passive control strategy in which the vent locations for the resin to arrive last are selected by conducting simulations of all possible permutations of anticipated variations. However as one can only choose limited number of vents, the yield improvement will be modest. To ensure success in most of the cases, two active control strategies, scenario based control and dependence map based control are introduced. Both strategies rely on flow arrival sensor feedback and use of auxiliary actuators to redirect the resin in areas that are unfilled. Scenario based control is based on anticipating the disturbance sites whereas dependence map based control relies on correcting the flow based on a target flow pattern. Simulations are used off-line to develop these strategies for the specific mold geometry and the results are transferred to a workstation that can implement them during the mold filling process in a laboratory experimental environment. Examples that demonstrate improvement in the filling behavior despite the disturbances are presented with experimental validation.

Biographical Sketch

Suresh G. Advani is an internationally recognized authority on modeling and simulation of composite manufacturing processes. His research interests are in rheology, fluid mechanics and heat transfer as applied to manufacturing processes especially for polymers and polymer composites, nano composites and more recently in fuel cells. He received his B Tech Degree in



Suresh G. Advani

Mechanical Engineering from I.I.T. Bombay, India in 1982 and joined University of Delaware in 1987 after receiving his Ph.D in Mechanical Engineering from University of Illinois at Urbana-Champaign. He has also served as Visiting Faculty at Imperial College in London and at University of Auckland in New Zealand. Advani was selected to be the Fellow of American Society of Mechanical Engineers in 1999 and is the North American Editor for the journal *Composites A: Applied Science and Manufacturing*. Professor Advani also serves on the Scientific Advisory Committee of Journal of Forming Processes and Flow Processes in Composites Manufacturing. He recently chaired an NSF workshop on Future of Modeling in Composite Manufacturing Processes. He has co-authored over 300 journal and conference proceeding articles and has contributed chapters in over twenty books. He recently co-authored a textbook on "Process Modeling in Composites Manufacturing". He has graduated 28 Masters and 17 Ph.D students of which six are currently faculty members at other universities.

Melt Infiltrated Ceramic Composites for Gas Turbine Applications

Gregory Corman
GE Global Research

Abstract

Although monolithic melt-infiltrated SiC ceramics have existed for about 40 years, they have not found application in gas turbine engine applications because of their propensity for brittle, catastrophic failure. This problem was overcome in the late 1980's by the development at GE of continuous fiber reinforced, melt infiltrated ceramic matrix composites (MI-CMC). This talk describes the constituents, fabrication processes, and properties of MI-CMC materials that GE is actively developing for gas turbine use, and that are now available commercially under the HiPerComp® trade name.

Biographical Sketch

Dr. Gregory Corman is a staff scientist at the GE Global Research Center in Niskayuna, NY. He received his PhD in Ceramic Science from Penn State University in 1984, and then worked for two years at the Westinghouse Research Center in Pittsburgh, PA, on the sintering of oxide nuclear fuels before joining GE Global Research in 1986. At GE, Dr. Corman has investigated various aspects of the processing and characterization of ceramic matrix composites and their constituents. For the last 14 years his concentration has been on the development of silicon carbide-based CMCs using a melt infiltration approach. Dr. Corman has over 20 publications and 14 patents related to his work on ceramic composites.

A Method for Evaluating Manufacturing Damage in Monolithic and Composite Materials

Dean Poeth
Adjunct Professor
The Graduate College of Union University
(518) 377-4041
dpoeth@worldnet.att.net

Abstract

Aerospace components fabricated from monolithic and composite materials can possess inherent discontinuities as a result of their manufacture. Eddy current, thermography, X-radiography, ultrasonic, replication, and acoustic emission testing have all been used to characterize composites with only limited success. Without the ability to evaluate internal damage, it can be difficult to evaluate and control the manufacturing process.

Neutron radiography, when used with a suitable contrasting penetrant, has the ability to image internal damage in composite and monolithic materials. Neutron radiography has the ability to view low atomic number materials (such as plastics and lubricants) inside high atomic number materials (such as steel and lead). Unlike X-ray photons, neutrons primarily interact with the nuclei of the object's constituent atoms. This results in neutron attenuation being significantly different (and complementary) to that of X-rays.

Biographical Sketch

Dean F. Poeth II, 218 Gower Rd., Schenectady, NY 12302 holds MS and Ph.D. engineering degrees from The Pennsylvania State University and a BS in engineering from The Ohio State University. He is a licensed professional engineer in Ohio and a member of the National Engineering Honors Society (Tau Beta Pi), Industrial Engineering Honors Society (Alpha Pi Mu) and Honors Society (Phi Kappa Phi). Dr. Poeth is an adjunct professor at the Graduate College of Union University in Schenectady, New York. He is an experienced lean/six sigma green belt and a certified manufacturing engineer.

Effective Thermal Conductivity of Composites by Eshelby's Method

Yozo Mikata
Lockheed Martin – KAPL, Inc.
P.O. Box 1072
Schenectady, NY 12301

Abstract

This talk will discuss the various methods to obtain effective material properties of particulate as well as fiber composites. A particular emphasis, however, will be placed on Eshelby's equivalent inclusion method, which can unify different approaches and different geometries. As an application of the method, effective thermal conductivities of unidirectional as well as cross-directional ceramic fiber composites are calculated as a function of the volume fraction of tow (ceramic fiber bundle) and the debonding ratio of the fiber.

Biographical Sketch

Dr. Mikata graduated from the University of Tokyo with B.S. and M.S. in Civil Engineering, and obtained Ph.D. from the University of Delaware in Mechanical and Aerospace Engineering. He has worked on many different research topics including geometrically nonlinear problems, finite element method, boundary element method, composite materials, elastic wave scattering by randomly oriented cracks, dynamic inclusion problems, piezoelectric Eshelby tensor, post-buckling of carbon nanotube, inverse problems in magnetostatics, heat conduction problems, shock and vibration, and ground water flow. He has also briefly worked in the telecommunication industry in the area of computer networks.

Keynote Talk

Monday Evening, May 22nd, 2006
Glen Sanders Mansion

Cocktails 6:00 p.m.

Dinner 7:00 p.m.

Keynote Talk 8:00 p.m.

The Substance of Civilization: Materials and Human History from the Stone Age to the Age of Silicon

Stephen L. Sass
Department of Materials Science and Engineering
Cornell University

Materials have enabled revolutionary advances in how we live, work, fight and travel, hence the naming of eras after them -- Stone, Bronze and Iron Ages. This talk explores the role of materials in the development of modern Western industrial civilizations, by putting technology into an historical and human context, examining the advances made possible by innovations with materials, starting with the Stone Age. Connections between critical developments are identified, for example, the relationship among materials, agriculture and written languages in the fourth millennium B.C., and among the Exodus of the Hebrews, the general tumult in the Eastern Mediterranean and the onset of the Iron Age, at the end of the second millennium B.C. The roles of China and Islam in stimulating advances in technology will be explored. Early technologies will be illustrated with beautiful works of art.

Biography

Stephen L. Sass, Professor of Materials Science and Engineering, joined the Cornell faculty in 1967. He received his B.Ch.E. from the City College of New York in 1961 and his Ph.D. in Materials Science from Northwestern University in 1966. He is a Fulbright Scholar at the Technische Hogeschool, Delft, The Netherland, 1966-67 and a Fellow of the American Physical Society and ASM International. In 2001, he was named a Stephen H. Weiss Presidential Fellow, a university-wide honor recognizing "effective, inspiring and distinguished teaching of undergraduate students". His research interests include the structure and properties of internal interfaces in solids and the development of methods for the fabrication of periodic surface structures with spacings on the nanometer-length scale. Stephen has more than 180 technical papers and 3 patents. In 1998, he published The Substance of Civilization: Materials and Human History from the Stone Age to the Age of Silicon, which was written to make science and technology accessible to non-scientists, by putting them into an historical and human context.

Interface Engineering

Session III

Chair: Seth Taylor, GE Global Research

Authors and Titles

Christopher Schuh (Massachusetts Institute of Technology)
Grain Boundary Engineering: Composite Modeling of Grain Boundary Networks

Elizabeth Dickey (Pennsylvania State University)
Effect of Local Oxygen Activity on Metal-Ceramic Interface Chemistry

Brian Sheldon (Brown University)
Toughening Mechanisms in Ceramic Composites Reinforced with Nanotubes and Nanofibers

James Howe (University of Virginia)
New Techniques for Determining the Properties of Materials and Interfaces during *In Situ* Heating in the TEM

William Egelhoff (National Institute of Standards and Technology)
Controlling Interfacial Structure in the Growth of Magnetic Thin Films

Grain Boundary Engineering: Composite Modeling of Grain Boundary Networks

Christopher Schuh
Department of Materials Science and Engineering
Massachusetts Institute of Technology

Abstract

In microstructural engineering, it is important to understand how the spatial arrangement of phases leads to ‘effective’ properties of the ensemble. In the context of composite materials, there are many homogenization methods and effective medium-type theories that provide such connections, and these are continually becoming more sophisticated. In “grain boundary engineered” materials, the composition and spatial distribution of different *grain boundary types* are manipulated, and can lead to dramatic property improvements. The properties of grain boundary networks can also be studied in the context of composite models and effective medium theory, but with the additional caveat that percolation phenomena are of particular importance in grain boundary engineering. This talk will present an overview of our work towards understanding and modeling the structure of grain boundary networks, with emphasis on intergranular diffusion and diffusional creep problems.

Biographical Sketch

Christopher A. Schuh is the Salapatas Associate Professor of Metallurgy in the Department of Materials Science and Engineering at MIT. He joined MIT in 2002, having received a B.S. degree at the University of Illinois at Urbana-Champaign (1997), and a Ph.D. at Northwestern University (2001), both in the field of Materials Science and Engineering. Prof. Schuh also held the Ernest O. Lawrence postdoctoral fellowship at Lawrence Livermore National Laboratory in 2001-2002. Prof. Schuh’s research is focused on structural metallurgy, and seeks to control disorder in metallic microstructures for the purpose of optimizing mechanical properties. He works with disorder at many scales, including the atomic level (in amorphous metals), the nano-scale (in nanostructured metals), as well as at more conventional microstructural scales (in grain boundary engineered materials). Prof. Schuh’s work has received international attention through several awards, including the Robert Lansing Hardy Medal of The Metals, Minerals, and Materials Society.

Effect of Local Oxygen Activity on Metal-Ceramic Interface Chemistry

Elizabeth Dickey
Pennsylvania State University

Abstract

The investigation of metal-ceramic interfaces by techniques such as transmission electron microscopy (TEM) imaging and spectroscopy can provide in-depth knowledge of atomic-level interface structure and chemistry. The dynamics of such interfaces, in terms of how they equilibrate with local changes in oxygen electrochemical potential, is not, however, well understood. This talk will explore how local oxygen activity at metal-ceramic interfaces, as modified by external PO_2 or DC bias, can have profound effects on interface chemistry and electrical properties. The Ni-BaTiO₃ interface, which is relevant to commercial multilayer ceramic capacitors, will be discussed in detail. Complementary impedance spectroscopy and TEM provide fundamental insight into the microchemical dynamics of these interfaces and the implications for current injection at the interfaces.

Biographical Sketch

Professor Elizabeth Dickey received her B.S. in Materials Engineering in 1992 from the University of Kentucky. She then pursued her Ph.D. in Materials Science and Engineering at Northwestern University under an NSF graduate research fellowship. Upon receiving her Ph.D. in 1997, Dr. Dickey returned to her home state to join the faculty of the Chemical and Materials Engineering Department at the University of Kentucky. In 2001 she moved to the Pennsylvania State University where she is currently an Associate Professor of Materials Science and Engineering. Her academic and research interests include nanomaterials for electrical and sensing applications, interface materials science and high-temperature ceramic composites. In 1999 she received the Presidential Early Career Award for Scientists and Engineers (PECASE). She is currently a John T. Ryan, Jr. Faculty Fellow in the College of Earth and Mineral Sciences at Penn State.

Toughening Mechanisms in Ceramic Composites Reinforced with Nanotubes and Nanofibers

Brian Sheldon
Division of Engineering
Brown University
Providence, RI 02912

Abstract

Ceramic composite coatings were fabricated with carbon nanotubes, carbon nanofibers, and SiC nanofibers as reinforcements. Materials with both aligned and randomly oriented reinforcements were studied, with unidirectional aligned nanotubes providing an excellent opportunity to investigate basic toughening mechanisms. The results demonstrate that these materials exhibit the same principle toughening mechanisms that are known to operate in more conventional ceramic composites, notably crack deflection, crack bridging, and nanotube pullout. Evidence of nanotube necking and buckling suggests that additional mechanisms may also contribute to the composite toughness. A detailed finite element model was developed to describe the deformation of the composite during nanoindentation. Applying this computational method to the experimental data shows that nanotube reinforcements can lead to significant toughening. This improved performance depends on the interfacial properties between the matrix and reinforcements, just as it does in conventional ceramic composites. However, controlling these interfaces is notably different because the diameters of the nanosized reinforcements are roughly two orders of magnitude smaller than conventional fibers.

Biographical Sketch

Brian W. Sheldon is Professor of Engineering at Brown University. He received both of his degrees from the Massachusetts Institute of Technology: S.B. in Chemical Engineering (1981) and Sc.D. in Ceramics (1989). Prior to his arrival at Brown he held research staff positions at the Amoco Research Center (1981-84) and Oak Ridge National Laboratory (1988-1991). Prof Sheldon's current research focuses on two general areas: stress evolution and mechanical behavior of thin films, and ceramic composites reinforced with nanotubes and nanofibers.

New Techniques for Determining the Properties of Materials and Interfaces during *In Situ* Heating in the TEM

James Howe
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Abstract

In situ transmission electron microscopy (TEM) is an indispensable tool for determining the behavior of materials and interfaces under different experimental conditions. This presentation focuses on two techniques that we have recently been using to determine the properties of materials during *in situ* heating in the TEM. These include: 1) energy-filtering transmission electron microscopy (EFTEM) combined with valence electron energy-loss spectroscopy (VEELS), which we are using to determine and map the mechanical and physical properties of materials at temperature, and 2) using a calibrated heating holder and a newly developed thermal shield for energy-dispersive X-ray spectroscopy (EDXS), to study the kinetics of interface motion and composition changes that occur in the solid and liquid phases, and across the interface, respectively, during solidification and melting. Results obtained by application of these techniques to Al and Ti-base alloys are presented and their potential in interface engineering is discussed. This research was supported by NSF under Grant DMR-9908855 and DOE under Grant DE-FG02-01ER45918.

Biographical Sketch

James M. Howe received his Ph.D. in Materials Science from the University of California, Berkeley in 1985 and joined the Department of Metallurgical Engineering and Materials Science at Carnegie Mellon University as an Alcoa Assistant Professor of Physical Metallurgy. In 1991, Dr. Howe moved to the Department of Materials Science and Engineering at the University of Virginia, where he serves as Director of the Electron Microscope Facility, and was promoted to Full Professor in 1999. His current research emphasizes the application of high-resolution and analytical transmission electron microscope techniques to study the mechanisms and kinetics of phase transformations in nanoparticles and the behavior of interphase boundaries at the atomic level. Dr. Howe has received several prestigious awards for his research, including a Senior Research Award from the von Humboldt Foundation (Germany) in 1999, the Materials Science Research Silver Medal from ASM International in 2000, the TMS Champion H. Mathewson Medal in 2005, and he was elected Fellow of ASM International in 1997. Dr. Howe has published over two hundred technical papers, two book chapters and two symposium proceedings on transformation interfaces and electron microscopy. He is author of the textbook "Interfaces in Materials", published in 1997, and co-author with Prof. B. Fultz, of a textbook "Transmission Electron Microscopy and Diffractometry of Materials", published in 2001.

Controlling Interfacial Structure in the Growth of Magnetic Thin Films

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Abstract

Magnetic thin films play an important role in ultrahigh-density data storage. Often, these films are complex structures that are tailored to have specific properties. These properties are usually very sensitive to the structure of interfaces, and there is a constant need for new strategies to improve interfacial control. This talk will present examples of these needs, and the strategies that were developed to meet them.

Biographical Sketch

Dr. Egelhoff received a Ph.D. in Physical Chemistry from Cambridge University in 1975. After a postdoc at Caltech and three years at General Motors Laboratories, he joined NIST in 1979. He has published over 200 papers and is a NIST Fellow and an APS Fellow.

Advanced Applications of Composites

Session IV

Chairs: Frank Johnson & Bernard Bewlay, GE Global Research

Authors and Titles

John Lewandowski (Case Western Reserve University)
**Flow, Fracture, and Fatigue Studies on Composites and Bulk
Metallic Glasses**

Joseph Lemsky (Ladish Co., Inc.)
**Dual Microstructure Heat Treatment for Advanced Turbine Engine
Components**

Walter Sherwood (Starfire Systems, Inc.)
**The Development and Commercialization of Polymer Derived
Ceramic Matrix Composites**

Charles Sullivan (Dartmouth College)
**Thin-Film Nano-Composite Soft Magnetic Materials for High
Frequency Applications**

Flow, Fracture, and Fatigue Studies on Composites and Bulk Metallic Glasses

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Leonard Case, Jr. Professor of Engineering
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Abstract

Composite materials provide combinations of properties not possible with conventional monolithic materials. The choice of matrix, reinforcement, and interfacial regions can significantly affect subsequent performance under quasi-static, cyclic, and dynamic test conditions. The presentation will begin with an overview of the mechanical behavior of various particulate reinforced composite materials (e.g. Aluminum MMCs) to illustrate the effects of volume fraction, particle size, and spacing on the toughness and fatigue behavior. This will be followed with a summary and comparison to bulk metallic glasses and their composites, with particular attention to their strength, toughness, and fatigue behavior. Included in the presentation will be recent experiments to determine the effects of changes in test temperature and loading rate on some of these properties. High speed testing at strain rates in excess of 1000/sec will be described, while high speed video has been used to record the deformation and fracture events operating under these extreme conditions. Potential uses of these materials in energy absorbing structures will be described.

Biographical Sketch

John J. Lewandowski received his B.S., M.E., and Ph.D. in Metallurgical Engineering and Materials Science at Carnegie Mellon University where he was a Hertz Foundation Fellow. After spending two years as a NATO Postdoctoral Fellow in the Department of Materials Science and Metallurgy at Cambridge University, England, working with Prof. John F. Knott, FRS, on fracture and fatigue of engineering materials, he became an Assistant Professor in the Department of Materials Science and Engineering at Case Western Reserve University. He is currently the Leonard Case Jr. Professor of Engineering, and Director of the Mechanical Characterization Facility. He has received the NSF Presidential Young Investigator Award, the SAE Ralph R. Teeter Educational Award, the ASM Bradley Stoughton Award for Young Teachers, the ASM Research Silver Medal, the CTSC Technical Educator Award, the Charles Hatchett Award from the Institute of Metals (U.K.) for work on Nb, and was elected an Overseas Fellow at Churchill College, Cambridge University, where he spent a sabbatical year for 2003-04. He has served on a number of panels organized by the National Research Council/National Academy of Sciences as well as the Institute of Mechanics and Materials at the University of California at San Diego. He was elected Fellow of ASM in 1995 and is past Chair of the ASM/TMS Joint Composites

Committee. His publications and presentations number in excess of 175 and 400, respectively, and are primarily in the areas of processing/structure/property relationships in ferrous and non-ferrous engineering materials; the effects of superposed pressure on deformation and fracture; fatigue and fracture of intermetallics and composites, bulk metallic glass, and layered/laminated materials; deformation processing; blast-resistant materials; and engineered materials systems.

Dual Microstructure Heat Treatment for Advanced Turbine Engine Components

Joseph Lemsky
Principle Metallurgical Engineer
Advanced Materials and Process Technology Group
Ladish Co., Inc.

Abstract

Dual property turbine engine disks is a concept where mechanical properties are tailored to distinctly different needs at the disk's bore and rim regions. Near the rim where the disk runs the hottest, creep strength and fatigue crack growth resistance limits the disk's life, whereas, near the bore tensile strength is critical to combat severe rotational stresses. Present engine disks are manufactured to uniform microstructures to balance mechanical properties, thus compromising the disk's full potential. Much work has been performed by turbine engine manufacturers and forging companies in the areas of dual alloy and dual microstructure disk processing. The presentation will briefly describe some work performed with dual alloy processes. Dual microstructure disk processing will be described in more detail. One technique, a NASA patented approach for dual microstructure processing, will be discussed in greater detail and will be the primary focus of the presentation.

Biographical Sketch

Joe Lemsky is a Principle Metallurgical Engineer in the Advanced Materials and Process Technology group at Ladish Co., Inc. He has worked in the areas of forging and heat treatment of turbine engine components for 24 years. Joe holds a B.S., Metallurgical Engineering, Michigan Technological University, 1980.

The Development and Commercialization of Polymer Derived Ceramic Matrix Composites

Walter J. Sherwood
Vice President of Technology
Starfire System, Inc.

Abstract

The method which Starfire has turned a laboratory curiosity material (\$10,000/kg) into a group of ceramic-forming polymer based systems that are now being utilized in brake rotors, brake pads, thermal protection systems, fire resistant coatings, and electronic packaging components will be described. Relevant data for each material system will be presented.

Biographical Sketch

Dr. Walter Sherwood founded Starfire Systems, Inc. in 1988 and is now Chairman of the Board and Vice President of Technology. After 12 years of managing Starfire alone, Dr. Sherwood brought in a professional management team in 2001. Since 2001, Dr. Sherwood has been Vice President of Technology and directs the research and commercialization programs at Starfire.

Dr. Sherwood received a B.S. in Physics, and both a M.S. and PhD in Materials Engineering from Rensselaer Polytechnic Institute. He has spent the last 16 years developing new high temperature ceramic materials utilizing ceramic-forming polymers. Prior to Founding Starfire, Dr. Sherwood developed the fabrication procedures and manufactured ceramic composite materials while employed as a senior engineer at Lockheed Martin-Knolls Atomic Power Laboratory (KAPL) from 1986 thru 1994. Dr. Sherwood also designed and supervised the building of the Composites Fabrication Laboratory at KAPL as well as designed and built a microwave processing system for ceramic and ceramic composites.

He currently holds three patents and has 8 more pending.

Thin-Film Nano-Composite Soft Magnetic Materials for High Frequency Applications

Charles R. Sullivan
Associate Professor
Thayer School of Engineering
Dartmouth College
Hanover, NH

Abstract

As electronic circuits get faster, magnetic materials used in inductors, transformers, and read-write heads must operate at higher frequency. Nano-composite magnetic materials, comprising magnetic metal nanoparticles in a ceramic matrix, can exhibit excellent soft properties into the GHz region, but they can also exhibit stripe-domain behavior, resulting in inferior performance. The origins of stripe-domain behavior and approaches to avoid it will be discussed. Applications to high-density high-frequency power converters will also be described.

Biographical Sketch

Charles R. Sullivan is Associate Professor at the Thayer School of Engineering, Dartmouth College, Hanover, NH. He received a B.S. from Princeton University in 1987 and a Ph.D. from the University of California, Berkeley in 1996, both in electrical engineering. His research includes magnetics design and optimization; thin-film magnetic materials and devices; and capacitor modeling. He is the recipient of a National Science Foundation CAREER award, an IEEE Power Electronics Society Prize Paper Award, and the Ross N. Tucker AIME Electronics Materials Award. He serves as Associate Editor for the Transactions on Power Electronics and Awards Chair for the Power Electronics Devices and Components Committee of IEEE Industry Applications Society.