2015 ASM SPRING SYMPOSIUM

Degradation of Materials

PROGRAM AND ABSTRACTS

May 18th & 19th, 2015
GE GLOBAL RESEARCH (GEGR)
NISKAYUNA, NEW YORK

Degradation of Materials

May 18th & 19th, 2015

GE Global Research
Niskayuna, New York

OBJECTIVES

Sponsored by the Eastern New York Chapter of ASM, 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.

2015 Spring Symposium Organizing Committee

Steve Buresh (GEGR), Symposium Committee Chair
Tom Angeliu (GEGR)
Stephen Bartolucci (Benet Labs)
Andy Detor (GEGR)
Voramon Dheeradhada (GEGR)
Laura Dial (GEGR)
Evan Dolley (GEGR)
Nell Gamble (GEGR)
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Matthew Kerr (KAPL)
Chris Klapper (GEGR)
Jenna Krotke (KAPL)
Jud Marte (GEGR)
Soumya Nag (GEGR)
Jo Newkirk (GEGR)
Scott Oppenheimer (GEGR)
Raul Rebak (GEGR)
Erica Sampson (GEGR)
Brittany Stiles (KAPL)
Monday, May 18th, 2015

7:30 - 8:30 Check-in/registration and coffee

8:30 - 8:40 Opening Remarks Steve Buresh – Symposium Committee Chair
8:40 - 9:10 Keynote Speaker: Tresa Pollock - Univ. of California Santa Barbara

Session I  Material Prediction / Modeling

Chairs: Matthew Kerr – Knolls Atomic Power Laboratory
       Jud Marte – GE Global Research

9:10 - 9:50 Jean Charles Stinville  Univ. of California Santa Barbara
Strain localization and fatigue damage: critical experimental data to assess the effect of the microstructure

9:50 - 10:30 Sommath Ghosh  Johns Hopkins University
Multi-Scale Crystal Plasticity FE Models for Predicting Fatigue in Polycrystalline Metals and Alloys

10:30 - 10:50 Break

10:50 - 11:30 Ellen Cerreta  Los Alamos National Laboratory
Damage Tolerant Microstructures for Extreme Environments

11:30 - 12:10 Anette Karlsson  Cleveland State University
Predicting fatigue crack propagation based on plastically dissipated energy

12:10 - 1:00 Lunch

Session II  Fatigue/Creep

Chairs: Vipul Gupta – GE Global Research
        Soumya Nag – GE Global Research

1:05 - 1:45 Wayne Jones  University of Michigan
Exploring Crack Initiation and Short Crack Growth in Advanced Structural Alloys in the Very High Cycle Fatigue (VHCF) Regime

1:50 - 2:30 Sean Agnew  University of Virginia
Characterization of Microstructure-Sensitive Fatigue Crack Growth Mechanisms in Precipitate Strengthened Al Alloys and a Brief Introduction to the Potential of Non-linear Acoustics for the Detection of Early Fatigue Damage

2:30 - 2:45 Break

2:50 - 3:30 Derek Warner  Cornell University
Harnessing Atomistic Modeling to Improve the Prediction of Fatigue Crack Growth

3:30 - 4:10 Sebastien Dryepondt  Oak Ridge National Laboratory
Cyclic Creep and Creep-Fatigue Testing of Gr91 Alloy in Air and Steam

4:45 - 5:45 Tour – GE Energy Learning Center -- 2690 Balltown Road Niskayuna, NY 12309
Monday evening, May 18th, 2015

Waters Edge Lighthouse Banquet Facility
Glenville, NY

6:00 - 7:00  Student Poster Session /Hors d’oeuvres and Cash Bar Reception (Waters Edge Banquet Facility)
7:00 - 8:00  Symposium Dinner
8:00 - 8:40 Dinner Talk: Frank Gayle

National Institute of Standards and Technology
Deputy Director
Advanced Manufacturing National Program Office

The Collapse of the World Trade Center Twin Towers
-A Metallurgist's View

Directions to Waters Edge Lighthouse Banquet Facility

2 Freemans Bridge Road
Glenville, NY 12302
(518) 370-5300

Take the first right off the traffic circle after exiting GE Global Research onto River Road (heading west)
Continue on River Road (turns into Providence Ave, after crossing Balltown Rd/Rt. 146) for 1 mile
Turn right at the light onto Hillside Ave.
Continue on Hillside Ave down the hill ~ 1.1 miles
Turn left onto Van Vranken Ave and then quickly veer right onto Maxon Rd.
Continue on Maxon for ~1 mile and turn right at the light onto Freeman’s Bridge Rd
The Waters Edge is just over the bridge on the right side.
The Banquet Facility is at the rear of the parking lot
Tuesday, May 19th, 2014

7:30 - 8:25  Check-in and coffee

Session III  Environmental Effects
Chairs:  Brittany Stiles  –  Knolls Atomic Power Laboratory

8:30 - 9:10  Peter Ford  Advanced Nuclear Technology International
  Materials Reliability in Boiling Water Reactors

9:10 - 9:50  Tyler Moss  Knolls Atomic Power Laboratory
  Accelerated Stress Corrosion Crack Initiation of Alloy 690 in Supercritical Water

9:50 - 10:30  Brian Somerday  Sandia National Laboratories
  A Comprehensive View of Gaseous Hydrogen-Assisted Cracking

10:30 -10:45  Break

10:45 - 11:25  Sunniva Collings  Case Western Reserve University
  Materials Degradation in the Semiconductor Industry

11:30 - 12:30  Lunch

Session IV  Mitigation / Monitoring
Chairs:  Tom Angeliu  –  GE Global Research

12:40 - 1:20  Young-Yin Kim  GE Global Research
  Electrochemical Approach for Developing the Life Extension Methodology of GE Boiling Water Reactor Components

1:20 - 2:00  Andrew Vackel  SUNY Stony Brook
  Thermal Spray Coatings for Structural Stabilization, Reclamation, and Service Life Extension

2:00 - 2:15  Break

2:20 - 3:00  Xi Shan  GE Oil and Gas
  Utilization of an Expert System for Selection of Metallic Materials for Production Wellbore Environments

3:00 - 3:40  Chris Mulligan  U.S. Army Benet Laboratories
  Surface Technologies for Armament Components

3:45 - 3:50  Concluding Remarks
2015 ASM SPRING SYMPOSIUM

Degradation of Materials

PROGRAM AND ABSTRACTS

May 18th & 19th, 2015

GE GLOBAL RESEARCH (GEGR)
NISKAYUNA, NEW YORK
**Keynote Speaker**

**Tresa Pollock**

**University of California, Santa Barbara**
**Alcoa Professor of Materials and Department Chair**
**Santa Barbara, California**

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**Biographical Sketch**

Professor Pollock is a world-renowned expert in the science and technology of advanced structural alloys with applications in aerospace, energy and automotive industries. She holds degrees from Purdue University (B.Sc. 1984) and MIT (Ph.D. 1989). Her professional career started at GE Aircraft Engines, where she worked in the development of advanced superalloys for gas turbine engines. In 1991 she joined the MSE faculty at Carnegie Mellon University, where she was Alcoa Professor until 1999. In 2000 she moved to the University of Michigan, where she held the L.H. and F.E. Van Vlack Professorship of Materials Science and Engineering. In 2010, she joined the Materials Department at UCSB where she is now serving as Chair of the Department.

Professor Pollock is the recipient of numerous honors and awards, most notably her election to the National Academy of Engineering in 2005 and election as TMS Fellow in 2009 “for seminal contributions in the understanding of high temperature alloys, and for distinguished leadership in materials education and the materials profession”. She has been honored both for her contributions to the literature (2008 AIME Raymond Award, 2005 Magnesium Technology Award) as well as for excellence in teaching (1995 ASM Stoughton Award) and overall professional accomplishment (1999 ASM Silver Medal, 205 IMR Lee Hsun Award, 2007 ASM Jeffries Lecture). Professor Pollock was TMS President in 2005.

Professor Pollock’s current interests include the mechanical and environmental performance of materials in extreme environments, unique high temperature materials processing paths, ultrafast laser-material interactions, alloy design and 3-D materials characterization. Her recent research has focused on thermal barrier coatings systems and platinum group metal-containing bond coats, new intermetallic-containing cobalt-base materials, vapor phase processing of sheet materials for hypersonic flight systems, growth of nickel-base alloy single crystals with a new liquid tin-assisted Bridgman technique, development of new femtosecond laser-aided 3-D tomography techniques and development of models for Integrated Computational Materials Engineering efforts.
Material Prediction / Modeling

Session I

Chairs: Matthew Kerr (KAPL) and Jud Marte (GEGR)

Authors and Titles

Jean Charles Stinville (University of California Santa Barbara)
Strain localization and fatigue damage: critical experimental data to assess the effect of the microstructure

Sommath Ghosh (Johns Hopkins University)
Multi-Scale Crystal Plasticity FE Models for Predicting Fatigue in Polycrystalline Metals and Alloys

Ellen Cerreta (Los Alamos National Laboratory)
Damage Tolerant Microstructures for Extreme Environments

Anette Karlsson (Cleveland State University)
Predicting fatigue crack propagation based on plastically dissipated energy
Strain localization and fatigue damage: critical experimental data to assess the effect of the microstructure

Jean Charles Stinville
University of California Santa Barbara
Santa Barbara, California

Abstract

Robust models for fatigue and the variability in this property could provide substantial enhancements to the design, processing and life prediction of alloy parts. A major challenge is the strong dependence of the intrinsic plastic deformation processes that operate during fatigue on the microstructure of the alloy involving localized accumulation of plastic strain and ultimately crack initiation and propagation. Thus, predictive models require formulation of constitutive laws that capture key grain-scale plasticity phenomena. In this context, statistical experimental data on strain localization and damage during cycling loading spatially correlated with the microstructure are critical. It has been found that specific microstructural configuration conditions must be satisfied for cracks to initiate and propagate. These statistically rare microstructural heterogeneities greatly affect the fatigue properties and the fatigue variability of a material. Therefore, approaches for convergence-based volume element sampling that link microstructural parameters to fatigue properties for component design have been developed. The approaches for volume element sizing are also essential to determine the representative size and resolution of the microstructure required for computational simulations of components to accurately predict the fatigue behavior. A methodology, combining experimental and processing data tools has been developed and adapted at the microstructural scale to allow direct comparison between simulations and experimental data.

Biographical Sketch

Jean-Charles Stinville is currently an Associate Research Specialist in the Materials Department at the University of California Santa Barbara (UCSB). His interests include the deformation behavior and damage of polycrystalline and monocrystalline materials in relation with their microstructure. A significant portion of his research involves the development of methodologies and experimental tools for the characterization of the stain localization and damage during cycling loading. Jean-Charles received his Ph.D in solid mechanics, materials science and structures mechanics from the Pprime Institute – University of Poitiers, France and his engineering degree in aeronautics from the French Grande Ecole ENSMA, Poitiers.
Multi-Scale Crystal Plasticity FE Models for Predicting Fatigue in Polycrystalline Metals and Alloys

Somnath Ghosh
Johns Hopkins University
Baltimore, Maryland

Abstract

The Integrated Computational Materials Science & Engineering or ICMSE initiative entails integration of information across length and time scales for relevant materials phenomena and enables concurrent analysis of manufacturing, design, and materials. Computational Mechanics plays an important role in this integration. This talk will present various modules in the development of a microstructure based modeling of fatigue crack initiation in polycrystalline alloys. The model implements crystal plasticity theory with explicit grain structures and the mechanical response of polycrystalline aggregates are deduced from the behavior of constituent crystal grains. These calculations provide a platform for the implementation of physics-based crack evolution criterion that accounts for the effects of microstructural inhomogeneity. Systematic development of a crystal plasticity-based fatigue crack nucleation model is conducted. The presentation will also discuss a wavelet transformation based multi-time scaling (WATMUS) algorithm for accelerated crystal plasticity finite element simulations. The WATMUS algorithm does not require any scale-separation and naturally transforms the coarse time scale response into a monotonic cycle scale without the requirement of sub-cycle resolution. The method significantly enhances computational efficiency in comparison with conventional single time scale integration methods. Adaptivity conditions are also developed for this algorithm to improve accuracy and efficiency. Finally the talk will discuss an approach to evaluate coupled crystal plasticity-damage evolution relations based on molecular dynamics simulations of a crystalline material with an embedded crack.

Biographical Sketch

Somnath Ghosh is the Michael G. Callas Chair Professor in the Department of Civil Engineering and Professor of Mechanical Engineering, and Materials Science & Engineering at Johns Hopkins University. At JHU, he is the founding Director of the Center for Integrated Structure-Materials Modeling and Simulation (CISMMS), and the Director/PI of the Air Force-JHU Center of Excellence in Integrated Materials Modeling (CEIMM). Prior to joining JHU, he was the John B. Nordholt Professor of Mechanical Engineering and Materials Science & Engineering at the Ohio State University till March 2011. He is currently the President of the United States Association of Computational Mechanics from 2014-2016 and a member of the IACM General Council.
Damage Tolerant Microstructures for Extreme Environments

Ellen Cerreta
Los Alamos National Laboratory
Los Alamos, New Mexico

Abstract

While material failure has been studied for many years, our current ability to predict and simulate evolving damage in extreme environments such as dynamic loading or irradiation conditions remains limited. One reason for this is the lack of understanding of the linkages between process-induced as well as evolved microstructure and damage. To this end, within the Materials Science in Radiation and Dynamic Extremes Group at Los Alamos National Laboratory, the role of microstructure on the early stages of damage has been studied in a number of metals, alloys and oxides using a combination of experiments and simulation. These multi-length scale studies have identified a number of linkages between damage nucleation and growth and microstructural features such as: inclusion/metal interface characteristics, bi-metal interfaces, grain boundary types, grain boundary orientation, and grain orientation. Here, the tools utilized to advance predictive models for damage in extreme environments as well as the work to design next generation materials for enhanced properties, particularly damage tolerance, will be discussed.

Biographical Sketch

Ellen Cerreta is the Group Leader for the Materials in Radiation and Dynamic Extremes Group (MST-8) at Los Alamos National Laboratory. She received her B.S in Aerospace Engineering from the University of Virginia and her M.S. and Ph.D. degrees in Materials Science and Engineering from Carnegie Mellon University. Ellen’s work has included the study of the mechanical behavior of materials and microstructural characterization with a focus on the relationship between microstructure and dynamic materials properties. At Los Alamos, Ellen leads a number of projects to investigate dynamic materials performance and utilizes this information to advance predictive capabilities for strength and damage in extreme environments. Ellen has been a member of ASM since 2004 and her volunteerism has included service: as a Key Reader for Materials Transactions A, on the ASM International Membership Committee from 2003-2009, and on the AM&P Editorial Board. Ellen is also an active member of TMS, where she is currently the Vice Chair of the Structural Materials Division.
Predicting fatigue crack propagation based on plastically dissipated energy

Anette Karlsson
Cleveland State University
Cleveland, Ohio

Abstract

Researchers and design engineers have traditionally relied on experimental characterizations to establish fatigue crack growth rates. This requires detailed specimen preparation, crack growth measurements and interpretation of raw data, which are all costly and time consuming.

We propose using a continuum based modeling approached, Finite Element (FE) simulations, to predict fatigue crack growth rates. FE modeling is a common tool used for designing engineering components, where, for example, the stresses induced by various load conditions can readily be analyzed and load limits based on fracture or yield criterion can be determined. However, in its basic formulation, FE simulations cannot predict the growth rate of a fatigue crack. Thus, we suggest augmenting the FE analysis with a method based on dissipated plastic energy to predict fatigue crack growth. In its simplest form, dissipated plastic energy is directly associated with plastic yielding, which is associated with dislocation motions in a ductile metal. Dislocation motions around a crack tip are, in turn, associated with fatigue crack growth.

In the FE-analysis, the crack advancement is governed by a propagation criterion that relates the plastically dissipated energy ahead of the crack tip to a critical value. Once this critical value is satisfied, crack propagation is modeled via a node release scheme. Thus, the crack growth rate is an output from the numerical simulation. The crack growth rate predicted by the proposed scheme is compared with experimental crack growth data in the Paris-regime for selected metals, showing a very good match. The numerical scheme is further extended to crack propagation in 3D to capture the crack front profile changes (crack tunneling) under cyclic loading. Moreover, the simulations show qualitative agreement with the temporary decrease of the crack grow rate after an overload.
Dr. Anette M. Karlsson is the Dean of the Washkewicz College of Engineering at Cleveland State University (CSU), Cleveland, Ohio. She received a Ph.D. in Mechanical and Aerospace Engineering at Rutgers University, New Jersey, in 1999, and conducted postdoctoral research at Princeton University, NJ, until joining the University of Delaware in 2002. At the University of Delaware, she was promoted through the ranks, and became the Department Chair of Mechanical Engineering from 2008, until joining CSU in 2012.

Dr. Karlsson research interest relates to the thermo-mechanical properties of advanced materials including composite structures, polymer fuel cells, thermal barrier systems, ultralight structures and instrumented indentation. She has published over 80 peer-reviewed international journal articles. Dr. Karlsson has received funding for her research from federal agencies such as Department of Defense, Department of Energy, Department of Transportation and the National Science Foundation. She has also secured long time funding from companies such as WL Gore and DuPont.

Dr. Karlsson is a Fellow of the American Society of Mechanical Engineering. She is a member of the American Society for Engineering Education, where she serves as a member of the Engineering Deans Council’s Diversity Committee.
Fatigue / Creep

Session II

Chairs: Vipul Gupta (GEGR) and Soumya Nag (GEGR)

Authors and Titles

*Wayne Jones (University of Michigan)*
Exploring Crack Initiation and Short Crack Growth in Advanced Structural Alloys in the Very High Cycle Fatigue (VHCF) Regime

*Sean Agnew (University of Virginia)*
Characterization of Microstructure-Sensitive Fatigue Crack Growth Mechanisms in Precipitate Strengthened Al Alloys and a Brief Introduction to the Potential of Non-linear Acoustics for the Detection of Early Fatigue

*Derek Warner (Cornell University)*
Harnessing Atomistic Modeling to Improve the Prediction of Fatigue Crack

*Sebastien Dryepondt (Oak Ridge National Laboratory)*
Cyclic Creep and Creep-Fatigue Testing of Gr91 Alloy in Air and Steam
Exploring Crack Initiation and Short Crack Growth in Advanced Structural Alloys in the Very High Cycle Fatigue (VHCF) Regime

Wayne Jones
University of Michigan
Ann Arbor, Michigan

Abstract
Transportation and energy systems are increasingly designed for fatigue lifetimes of $10^9$ cycles or longer. In this long-life regime, where stresses are nominally elastic, microstructure and microstructure variability play critical roles in fatigue crack initiation and short fatigue crack propagation. Fortunately, recent advances in the application of resonant fatigue instruments that operate at nominal frequencies of 20 kHz have provided a practical means of investigating fatigue behavior at these hard-to-access lifetimes. Such studies have increased our understanding of the mechanisms of fatigue damage accumulation and are currently supporting the development of realistic microstructure-based life prediction models in the VHCF regime. This presentation describes the use of ultrasonic fatigue methodologies to examine fatigue behavior in the VHCF regime in a range of structural alloys, including Ni-base superalloys, titanium alloys and magnesium alloys. Our recent development of in-situ UF-SEM ultrasonic fatigue instrumentation, which enables high-resolution, time-resolved studies of crack initiation and short crack growth in vacuum and in various environments, is also described.

Biographical Sketch
J. Wayne Jones is an Arthur F. Thurnau Professor of Materials Science and Engineering. He holds a Ph.D. in materials science from Vanderbilt University. His research interests focus on developing an understanding of structure-property relationships in advanced structural materials for automotive and aerospace applications. His work has centered on the fatigue and creep behavior of aluminum alloys, particulate strengthened aluminum matrix composites, titanium and titanium aluminides and more recently on new magnesium alloys. His research group is currently focusing on development of new instrumentation and techniques for studying the fatigue behavior of structural materials in the very high cycle fatigue regime using ultrasonic fatigue. He served as Associate Dean for Undergraduate Education in the College of Engineering from 1996 to 2001 and as interim chair of MSE in 1992. From 2008 to 2013 he was the associate director of the ADVANCE Program at UM. He served as president of TMS in 1999 and has served on the boards of directors of TMS and the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME). He was elected a fellow of ASM International in 2000. In 2007 he received the Harold H. Johnson Diversity Award from the University of Michigan. In 2010 he received ASM International’s Alfred Easton White Distinguished Teacher Award, the societies highest honor for materials science teaching excellence. In 2011 he and his co-authors were awarded the Champion H. Mathewson Medal for "Microstructural Influences on Very-High-Cycle Fatigue-Crack Initiation in Ti-6246" published in Metallurgical and Materials Transactions A, in 2008.
Characterization of Microstructure-Sensitive Fatigue Crack Growth Mechanisms in Precipitate Strengthened Al Alloys and a Brief Introduction to the Potential of Non-linear Acoustics for the Detection of Early Fatigue

Sean Agnew
University of Virginia
Charlottesville, VA

Abstract

The motivation for the investigations discussed in this presentation is that simplified models for predicting fatigue are conservative (costly) and impede fleet “readiness,” and the development of physics-based multi-stage fatigue models can address this drawback. However, development of the models requires high resolution experimental data, and a better understanding of the mechanisms of initiation and small-crack growth. The importance of testing environment is emphasized throughout the presentation. Techniques to determine the crystallography of fatigue fracture surface features are presented, which are based upon SEM fractography combined with EBSD. The so-called marker banding technique is employed to clearly identify fatigue crack initiation sites and the early stages of crack growth. EBSD assessments of orientation gradients are used to indirectly explore the dependence of the fatigue crack path on the dislocation structure. Direct TEM examination of the dislocation structure, using samples produced by focused ion beam milling of samples from the crack wake, are used to assess the impact of environment on the development of these dislocation structures.

Finally, a brief introduction will be given regarding the potential which acoustic nonlinearity presents for quantifying even pre-crack damage. For example, dislocations generated during cyclic loading of metals self-organize into substructures that produce substantial changes in the nonlinear response. TEM measurements of the volume fractions of veins and persistent slip bands, dislocation loop lengths, dipole heights and the densities of primary and secondary dislocations are obtained from Cu single crystals fatigue tested under single slip orientations, at constant plastic strain amplitude. These measurements provide input for the Cantrell model of nonlinearity, which are compared with experimental measurements of the same. The potential and limitations of the approach will be discussed.
**Biographical Sketch**

Sean R. Agnew began studying engineering at Clarkson University in his hometown, Potsdam, New York. He completed a B.S. in Mechanical Engineering and Materials Science and Engineering at Cornell University in 1994. He obtained a Ph.D. in Materials Science and Engineering at Northwestern University in 1998, for his critical assessment of severe plastic deformation as a means to produce ultrafine grained metals. He held a Wigner Fellowship at Oak Ridge National Laboratory from 1999-2001. He then joined the faculty at the University of Virginia, where he is now Professor of Materials Science and Engineering. His research interests include mechanical behavior of materials, especially crystal plasticity, diffraction-based characterization, and non-destructive evaluation. He is best known for his contributions to understanding the deformation of Mg alloys, including the roles of non-basal slip and mechanical twinning, and their relationships with crystallographic texture, internal stresses, and anisotropy. He has published approximately 140 scientific articles.
Harnessing Atomistic Modeling to Improve the Prediction of Fatigue Crack

Derek Warner
Cornell University
Ithaca, New York

Abstract

The prediction of crack growth is one of the most technologically important and scientifically intriguing problems in mechanics of materials. Yet, despite decades of research, a comprehensive understanding of the process has remained elusive. As a quintessential multiscale phenomenon, crack growth is both a chemical and mechanical process, involving interatomic bond breakage driven by long range mechanical stress fields. Thanks to growing supercomputing resources and novel concurrent multiscale modeling techniques that can accurately couple quantum and continuum mechanics modeling domains, crack tip processes in real environments are just now becoming accessible to powerful quantum chemistry approaches such as Kohn Sham Density Functional Theory. The majority of our work in this area has been focused on understanding how surface impurity elements influence the behavior of cracks in aluminum, a material that serves as the base of many technologically important alloys whose fracture response is known to be affected by chemical environment. In this talk, I will review our work on this topic and use it to frame our ongoing work.

Biographical Sketch

Derek Warner is an Associate Professor in the School of Civil and Environmental Engineering at Cornell University. Prior to his arrival at Cornell in 2007, he was a Postdoctoral Research Associate in the Division of Engineering at Brown University, where he worked in the Mechanics of Solids Group. He completed his Ph.D. in Mechanical Engineering at Johns Hopkins University in 2006. He has held visiting appointments at the US Army Research Laboratory and École polytechnique fédérale de Lausanne in Switzerland. He is currently the director of the Cornell Fracture Group, which conducts both scientific and engineering research aimed at understanding and predicting the deformation and failure of structures.
Cyclic Creep and Creep-Fatigue Testing of Gr91 Alloy in Air and Steam

Sebastien Dryepondt
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Abstract

Fossil-fueled power plants incorporated into any future energy portfolio will be required to be capable of flexible operation. This mode of operation will involve frequent load cycling and an increased number of shut-down events, resulting in significant thermo-mechanical cycling superimposed on the expected creep loading. Cyclic creep with loading/unloading sequences every 10h was therefore conducted on gr91 alloy at 550-650ºC, and the impact on the alloy creep properties was found to depend on the testing temperature. Creep-fatigue testing with hold time varying from 10min to 1h was also initiated at 625ºC, and the effect of creep damage increase on the creep-fatigue lifetime will be discussed. Finally, creep tests in steam were conducted at 650ºC on gr91 alloy and a fully ferritic 9Cr-1Mo alloy. Results showed a beneficial effect of steam due to the formation of a thick load-bearing oxide scale. Similar creep tests with the temperature decreasing down to 250ºC every 10h led to a decrease of specimen lifetime, and the impact of thermal cycling on the growing oxide scale will be discussed.

Biographical Sketch

Dr. Sebastien Dryepondt has been working on the durability of high temperature materials and coatings for the past 15 years, with a focus on the interaction between corrosion and mechanical deformation mechanisms. Research topics include the effect of oxidation in air or steam on the creep performance of Fe and Ni-based alloys, the oxidation behavior and lifetime modeling of high temperature oxide dispersion strengthened (ODS) FeCrAl alloys, and the deformation and cracking of oxidation-resistant coatings during thermo-mechanical testing. Dr. Dryepondt is currently the principal investigator of projects related to the development of new ODS FeCrAl alloys for accident-tolerant fuel cladding, the characterization of alumina-forming austenitic (AFA) foils for microturbine recuperators, and the development of creep-fatigue-oxidation lifetime models.
The Collapse of the World Trade Center Twin Towers - A Metallurgist's View

Dr. Frank W. Gayle
Deputy Director, Advanced Manufacturing National Program Office
National Institute of Standards and Technology

Abstract
The National Institute of Standards and Technology conducted a 4 year investigation of the World Trade Center tragedy at the request of Congress. The investigation addressed many aspects of the catastrophe, from occupant egress to factors affecting how long the Towers stood after being hit by the airplanes. This talk will describe the metallurgical analysis of structural steel from the Twin Towers, including characterization of mechanical properties and failure modes. In addition, major results and conclusions of the NIST Investigation will be presented, along with changes in building codes resulting from recommendations by NIST.

Biographical Sketch
Dr. Frank W. Gayle is Deputy Director of the Advanced Manufacturing National Program Office (AMNPO), an interagency team with participation from all Federal agencies involved in U.S. manufacturing. The AMNPO reports to the Executive Office of the President and is tasked with facilitating the President’s initiative in Advanced Manufacturing. A priority focus area for the office is establishment of the National Network for Manufacturing Innovation, a network of industry-led, private-public partnerships focused on manufacturing innovation.

Prior to joining the AMNPO in December 2012, Dr. Gayle spent 25 years in the Metallurgy Division of the National Institute of Standards and Technology, in positions from research metallurgist to Division Chief. His personal research at NIST focused on physical metallurgy of metals and alloys, including lead-free solders, quasicrystals, and aerospace materials from the Wright Flyer to the Space Shuttle. He also led a team of experts addressing steel forensics in the NIST Investigation of the collapse of World Trade Center Towers, evaluating steel recovered from Ground Zero to determine the mechanical properties, behavior under impact and high temperature conditions, and performance against specifications.

Dr. Gayle holds a Doctor of Science in Metallurgy from the Massachusetts Institute of Technology. He also earned a BS in Civil Engineering and a MS in Materials Science from Duke University. Prior to coming to NIST, Dr. Gayle spent 11 years in industry in the field of alloy development for aerospace applications.
Environmental Effects

Session III

Chair: Brittany Stiles (KAPL)

Authors and Titles

Peter Ford (Advanced Nuclear Technology International)  
Materials Reliability in Boiling Water Reactors

Tyler Moss (Knolls Atomic Power Laboratory)  
Accelerated Stress Corrosion Crack Initiation of  
Alloy 690 in Supercritical Water

Brian Somerday (Sandia National Laboratory)  
A Comprehensive View of Gaseous Hydrogen-Assisted Cracking

Sunniva Collins (Case Western Reserve University)  
Materials Degradation in the Semiconductor Industry
This tutorial is in two parts. The first addresses the current state of the nuclear power industry where materials reliability is an important issue. The second part concentrates on one materials degradation mode, stress corrosion cracking of stainless steels in Boiling Water Reactors, in order to demonstrate the development of predictive approaches to degradation, which reinforce the decisions required for long term mitigation strategies.

17% of the commercial power in 33 countries is supplied by nuclear energy from 444 reactors with different configurations of fuel (U\textsuperscript{235}), moderator (graphite, H\textsubscript{2}O, D\textsubscript{2}O), coolant (H\textsubscript{2}O, D\textsubscript{2}O, CO\textsubscript{2}, He, Na) and control material (Hf, B\textsubscript{4}C). There are 104 commercial reactors in the US, all being cooled and moderated by “light” water; these reactors supply 20-25% of the nation’s power requirements. Currently there are 51+ reactors under construction worldwide with the majority being in China (16), Russia (9), India (6) and S. Korea (6).

Thus the \textit{global} nuclear power industry is mature and growing. The US nuclear power industry is certainly mature, but its growth has been stymied by periodic changes in regulatory position and the public perception of “safety”.

The first commercial power plant was a 60 MWe Pressurized Water Reactor (PWR) commissioned in May, 1958 at Shippingport, Pa, whose design drew from the lessons learned during the development of the nuclear navy. In the subsequent 10 years 221 PWRs and Boiling Water Reactors (BWR’s) were ordered. However as the power of these commercial reactors increased, so concerns were expressed by the NRC about the reliability of the Emergency Core Cooling Systems (ECCS) that were needed to rapidly remove the decay heat created during a severe accident. This led to construction and costly delays associated with redesign of the ECCS.

Unfortunately in the period of the mid-1960’s and 1970’s an increasing number of materials degradation issues arose which led to unacceptably long outage times and low capacity factors, and increases in costs due to repair and replacement of damaged piping and core components. The choice of the replacement structural materials (e.g. concrete containment) and alloys (zirconium alloy fuel cladding, carbon and low alloy steels, nickel-base alloys and stainless steels) were crucial since they act as barriers to the release of radioactive material to the public.

These material degradation issues contributed to financial and technical factors that led to the cancellation of 95 orders and 23 early decommissions. The situation was not improved with regard to public acceptance of nuclear power due to severe accidents at Three Mile Island in 1979, Chernobyl in 1986 and, more recently, Fukushima in 2011.
In 2005 an Energy Bill addressed the developments required to meet future energy needs and, at the same time, limited the toxic emissions emanating from traditional fossil-fuel stations. Nuclear power was an obvious candidate with three interacting approaches;

- Build new reactors that were significantly different in design from the current BWR and PWR designs. In general these involved different core cooling media such as gas, liquid metal, supercritical water, molten salts, etc.
- Develop designs that were “evolutionary” from the current reactors with “passive” features that released large volumes of water onto the core of the reactor during a severe accident. In these cases the calculated core damage frequency was significantly reduced from that for the existing reactors.
- Extend the operating license and increase the power output of the existing BWRs and PWRs from 40 to 60 years (and potentially 80 years).

In all three of these cases materials reliability has been a key issue, especially given the harsh radiation environments and the extended operational times. The second half of the tutorial addresses the third of the above options, and discusses the development of a proactive approach for the management of material degradation rather than the reactive approach that has been used in the past. There are numerous degradation modes that need to be addressed (pitting, crevice corrosion, flow accelerated corrosion, radiation induced embrittlement, etc.), but, in this instance, emphasis is placed on the prediction and mitigation of stress corrosion cracking of stainless steels in BWRs.

**Biographical Sketch**

Peter Ford received his undergraduate and doctoral degrees in Metallurgy from Cambridge University, UK, and a master’s degree in Materials Science from RPI. The majority of his professional life has been at the General Electric Global Research Center where, for 20 years, he was manager of the Corrosion Mitigation and Coating Programs. Much of this effort centered on resolving problems of environmentally-assisted degradation of structural alloys in Boiling Water Reactors, the topic of this tutorial.

After retirement in 2000 he served as a full time member of the Advisory Committee on Reactor Safeguards (ACRS). This committee advises the commissioners of the NRC on diverse issues spanning, for example, certification of new reactor designs, license renewal for existing light water reactors, plant security and fuel reprocessing. For the last 9 years he has been associated with the consulting company, Advanced Nuclear Technology International that has customers from nuclear power utilities, reactor manufacturers, regulators and national laboratories who seek independent advice on operational issues.

He has authored approximately 100 papers and chapters in technical books. He is the recipient of several awards including the Whitney Award in 1995 from the National Association of Corrosion Engineers (NACE) for “contributions to corrosion science”, and the GE GRC Dushman Award in 1994 presented to the team “making a contribution of both significant scientific innovation as well as business value”
Accelerated Stress Corrosion Crack Initiation of Alloy 690 in Supercritical Water

Tyler Moss
Knolls Atomic Power Laboratory
Niskayuna, New York

Abstract

Stress corrosion crack (SCC) initiation of highly resistant materials can be studied by conducting accelerated testing as long as there is no change in the cracking mechanism. The objective of this work is to determine if accelerated SCC initiation testing of Alloy 600 and Alloy 690 can be conducted without changing the mechanism of crack initiation between subcritical and supercritical water. Unfortunately, the mechanism of crack initiation of these alloys is not known. This makes demonstrating whether there is a change in the SCC mechanism dependent on determining if there is a change in the oxidation, stress corrosion crack initiation morphology, and the temperature dependence of crack initiation between subcritical and supercritical water.

The corrosion environment was maintained at a fixed electrochemical potential above the Ni/NiO phase transition in the NiO stable regime by controlling the dissolved hydrogen concentration, with the location of the boundary determined by exposures of pure nickel. Exposures of unstressed corrosion coupons of Alloy 600 and 690 were conducted in hydrogenated subcritical and supercritical water for characterization of the oxide morphology, structure, and composition. Tensile bars of Alloy 600 and Alloy 690 were strained in constant extension rate tensile experiments in both environments to characterize the crack initiation morphology and to determine the temperature dependence of crack initiation.

The oxidation for both alloys was consistent between subcritical and supercritical water, composed of a multi-layer oxide structure composed of particles of NiO and NiFe$_2$O$_4$ formed by precipitation on the outer surface and a chromium rich inner oxide layer formed by diffusion of oxygen to the metal-oxide interface. The crack initiation morphology of Alloy 690 was consistent between subcritical and supercritical water, and a mechanism of crack initiation was developed. The SCC initiation temperature dependence of both alloys shows no discontinuity or change in slope in the activation energy at the critical point. All available evidence supports a consistent mechanism of stress corrosion crack initiation in both hydrogenated subcritical and supercritical water for Alloy 600 and Alloy 690.

Biographical Sketch

Tyler recently joined Knolls Atomic Power Laboratory as a Senior Materials Engineer after completing his Ph.D. thesis work on stress corrosion crack initiation of nickel based alloys at The University of Michigan under the guidance of Dr. Gary Was.
A Comprehensive View of Gaseous Hydrogen-Assisted Cracking

Brian Somerday
Sandia National Laboratories
Livermore, California

Abstract

This presentation unites three research stories to illustrate that gaseous hydrogen-assisted cracking is most effectively rationalized by recognizing and analyzing its multiple components. Each research story focuses on an essential component in the gaseous hydrogen-assisted cracking process, i.e., hydrogen-material interactions leading to damage, crack-tip stress and strain fields driving hydrogen-induced damage, and gas-surface interactions governing crack-tip hydrogen uptake. The presentation opens with an example of hydrogen-material interactions leading to damage in the form of cracking along grain boundaries. The significant outcome is demonstrating that grain-boundary orientation affects the propensity for hydrogen-induced cracking along these boundaries. The next research story features results uncovered while exercising two conventional methods for measuring gaseous hydrogen-assisted cracking thresholds for martensitic pressure vessel steels. Unexpectedly, thresholds measured under constant-displacement loading were higher than thresholds measured under rising-displacement loading. These varying threshold measurements can be attributed to fundamentally different crack-tip strain fields for test methods involving propagating cracks (constant-displacement loading) vs. stationary cracks (rising-displacement loading). The presentation then concludes by describing a study that systematically characterizes trace oxygen effects on gaseous hydrogen-accelerated fatigue crack growth for lower-strength ferritic steels. Specifically, experimental results reveal that oxygen-modified, hydrogen-accelerated fatigue crack growth is a function of oxygen concentration, load-cycle frequency, and load ratio (R). The interplay between these variables is ultimately related to the extent of oxygen adsorption on the crack-tip surface, which retards hydrogen uptake and the onset of hydrogen-accelerated cracking. Based on the assumption that oxygen diffusion through the crack channel is the rate-limiting step for adsorption, an analytical model is developed that quantifies the effects of salient environmental and mechanical variables on hydrogen-accelerated fatigue crack growth.
Biographical Sketch

Brian Somerday is a Distinguished Member of the Technical Staff in the Hydrogen and Materials Science Department at Sandia National Laboratories in Livermore, California. During his 17-year career at Sandia, he has led the core capability in hydrogen embrittlement, anchored by the Hydrogen Effects on Materials Laboratory. He is the principal investigator for projects that impact a range of technologies, including hydrogen fuel infrastructure, nuclear power, oil refining, and national defense. These projects focus on characterizing mechanical properties of structural metals in hydrogen gas, enabling materials selection and life prediction for components operating in hydrogen environments. Brian is actively involved in the international hydrogen embrittlement community, highlighted by co-organizing the 2008 and 2012 International Hydrogen Conferences at Grand Teton National Park. In addition to co-editing the two conference proceedings, he has also co-edited the book Gaseous Hydrogen Embrittlement of Materials in Energy Technologies. He received his PhD in materials science from the University of Virginia in 1998.
Materials Degradation in the Semiconductor Industry

Sunniva Collins
Case Western Reserve University
Cleveland, Ohio

Abstract

In semiconductor gas delivery systems, corrosion depends on many factors, such as:
•gas concentration and purity
•moisture content
•temperature
•localized inhomogeneities in material
•flow rates, time and frequency of exposure
Most of these factors are controlled by system operating parameters and protocols.
This presentation will give an overview of the current materials, surface treatments, and system assembly methods (welding) to minimize the potential for corrosion.
Review of standard test methods for corrosion and surface analytical techniques specific to this industry will also be addressed.

Biographical Sketch

Sunniva Collins joined the faculty of the Case School of Engineering at Case Western Reserve University in March 2013, where she teaches Materials, Design, and Manufacturing courses. Prior to CWRU, Collins was employed by Swagelok Company for 18 years in technical specialist and engineering management positions. Collins received her doctorate and master’s degree in materials science and engineering from Case Western Reserve University and her bachelor’s degree from the University of Michigan. She has worked to develop key standards on welding, surface finish requirements, and corrosion test methods for the semiconductor equipment industry. She has also instructed courses for ASME on Bioprocessing Equipment (BPE) and for the International Society of Pharmaceutical Engineers (ISPE). Her recent research concerns surface hardening of austenitic stainless steels by low temperature carburization. Collins is a Fellow of ASM International (FASM) and Alpha Sigma Mu, and serves as ASM’s President in 2014-2015.
Mitigation / Monitoring

Session IV

Chair: Tom Angeliu (GEGR)

Authors and Titles

Young-Yin Kim (GE Global Research)
Electrochemical Approach for Developing the Life Extension Methodology of GE Boiling Water Reactor Components

Andrew Vackel (SUNY Stony Brook)
Thermal Spray Coatings for Structural Stabilization, Reclamation, and Service Life Extension

Xi Shan (GE Oil and Gas)
Utilization of an Expert System for Selection of Metallic Materials for Production Wellbore Environments

Chris Mulligan (U.S. Army Benet Laboratories)
Surface Technologies for Armament Components
Electrochemical Approach for Developing the Life Extension Methodology of GE Boiling Water Reactor Components

Young-Yin Kim
GE Global Research
Niskayuna, New York

Abstract
Intergranular stress corrosion cracking (IGSCC) of structural components in GE boiling water nuclear reactors (BWR) compromises the availability of these power plants. Electrochemical corrosion potential (ECP) is a primary controlling factor in IGSCC susceptibility of structural materials in high temperature water, both under non-irradiated and irradiated conditions. The ECP is known to be controlled by the effective dissolved O₂, H₂O₂ and H₂ concentrations. By lowering the ECP of stainless steel (SS) below a critical potential (-230 mVshe), the susceptibility to IGSCC is markedly reduced.

The most efficient way to reduce the ECP is to use noble metals to catalyze the recombination of H₂ with O₂ and H₂O₂ on the metal surface and thereby mitigate the crack growth rate with minimal negative impact on BWR operation. The application of noble metals (Pt) to mitigate IGSCC in a commercial BWR was first demonstrated in 1996. Since then 45 BWRs worldwide have applied the NobleChem™ process just before end-of-cycle shutdown and/or during a mid-cycle shutdown or On-line NobleChem™ (OLNC) in which noble metals were applied under normal plant operating conditions. It has been well proven that mitigation effectiveness was achieved with an injection of a few ppb level (even at <1ppb at some plants) of Pt at worldwide BWR plants.

This presentation summarizes the fundamental understanding of the IGSCC mechanism and the development of its migration methods.

Biographical Sketch
Since joining the GEGRC in 1989, his work includes electrochemical kinetics and corrosion failure mechanisms of engineering materials under conditions of interest for power generation systems, such as turbine, generator, nuclear reactor, etc. He is the author of over 100 technical publications in the area of electrochemistry and corrosion science and holds 35 USA patents. He also has given many invited lectures at technical and educational symposia.
Thermal Spray Coatings for Structural Stabilization, Reclamation, and Service Life

Andrew Vackel
SUNY Stony Brook
Stony Brook, New York

Abstract

Thermal Spray, a melt-deposition coating technology, has long been used both as barriers to hostile environment degradation (wear, corrosion, heat etc.), but also as a means to repair metal components that have lost material throughout service life due to the service environment. However, most of these repairs are limited to either cosmetic or dimensional restoration, where the material added by spraying is not considered to play a role in the load bearing or mechanical aspects of the part. With the advances made in thermal spray process hardware, controls, and process specific sensors, thermal spray coatings may be processed and engineered to offer load bearing capability and/or fatigue life credit, opening up the possibilities for thermal spray coatings to be used as an advanced repair technology that goes beyond its historical role for simple dimensional restoration, combined with the coating’s role of surface protection, to create a structurally integrated coating.

This talk will explore the processing intricacies involved in the design, as well as the testing methodologies, of structurally integrated coatings associated with load bearing and fatigue life enhancement.

Biographical Sketch

Andrew Vackel is a Materials Science and Engineering Ph.D. candidate within the Center for Thermal Spray Research at SUNY Stony Brook under Prof. Sanjay Sampath. His research interests have been on thermal spray coatings produced via High Velocity Oxy-Fuel (HVOF), with particular focus on the aspects of coating processing and presence on the fatigue life of coated components. Part of his research was industrially funded through Safran Messier-Bugatti-Dowty, investigating the process-property-performance relationship of HVOF sprayed WC-CoCr. Other funding for his studies came from the Consortium for Thermal Spray Technology at Stony Brook, which includes 35+ industrial and research members in the thermal spray community. Additionally, Andrew was awarded the International Thermal Spray Association’s (ITSA) graduate student scholarship in 2013.

Prior to graduate school, Andrew spent two years as a contracted worker in the thermal spray group at General Electric’s Global Research Center in Niskayuna NY. He received his B.S. in Chemical Engineering from Clarkson University in 2008.
Utilization of an Expert System for Selection of Metallic Materials for Production Wellbore Environments

Xi Shan
GE Oil and Gas
Houston, Texas

Abstract
The production of oil and gas involves various environments. In acidizing process, concentrated HCl up to 28% is used to dissolve limestone and increase the permeability of the reservoir rock. Generally the produced fluid does not contain oxygen, however, chloride, H2S, CO2 are often present in the produced fluid. The presence of H2S and CO2 in the produced fluid lowers the pH of the produced water, and leads to various corrosion and cracking issues. The production equipment may also be used for injection of water, H2S and CO2 back into the formation for waste disposal or enhancing production, and the presence of oxygen in injected fluid can significantly increase the corrosivity.

The selection of materials for oil and gas production requires significant knowledge of materials behavior and experience. In order to select appropriate materials for a given application, it is necessary to understand the role of various factors that affect the performance of materials in such environments. Software Socrates is the tool currently used by GE Oil & gas for material selection. Socrates is a comprehensive corrosion resistant alloy selection system developed by Honeywell for corrosive oil and gas applications. It evaluates a number of parameters for the wellbore environment and provided an estimate of corrosion rate of steel and a list of possible corrosion-resistant alloys for the application.

In this presentation, factors affecting corrosion of metals in oil production are reviewed and demonstrated with the software Socrates, and methods of material selection for oil production wellbore environment are introduced.

Biographical Sketch
2013 –present, Staff Engineer, GE Oil & Gas, Houston, TX
2011 – 2013, Senior Engineer, Whirlpool Corporation, Benton Harbor, MI
2009 –2011, Research Assistant Professor, Corrosion and Reliability Engineering, U. of Akron
2004 –2009, Senior Research Associate, Case Western Reserve U.
1993 –1998, Materials Engineer, Central Iron and Steel Research Institute, Beijing, China

EDUCATION
Ph.D., Materials Science and Engineering, 2004
Case Western Reserve University, Cleveland, OH
Surface Technologies for Armament Components

Chris Mulligan
U.S. Army Benet Laboratories - ARDEC
Watervliet, New York

Abstract
Corrosion, wear, and thermal degradation of steel and other engineering materials remain a costly and significant problem across a wide array of applications. For armament components, steels remain some of the most important engineering materials due to their combination of low cost, high strength, machinability, and formability. However, along with many other engineering materials, they generally lack the requisite properties to perform on their own in extreme environments. Numerous manufacturing processes exist to modify the surface of steels to provide improved corrosion, wear, or thermal degradation resistance. Surface coatings come in both organic (e.g. paints, polymer coatings, etc.) and inorganic (metal plating, oxide and phosphate conversion coatings, galvanizing, etc.) forms. Organic coatings of course have limitations at high temperatures, so when a combination of wear, corrosion, and high temperature resistance is required, manufacturing processes such as electroplating and electroless plating are commonly used. Other manufacturing processes such as those based on thermal spray and vapor deposition processes are similarly used. For components in the unique armament environment, it is often difficult to find “off-the-shelf” alternatives to provide the perfect balance of wear, corrosion resistance, and high temperature resistance amongst the vast array of manufacturing processes available. This talk will discuss some of the unique materials challenges encountered in the armament environment and research conducted on both metallic and nitride based vapor deposited coatings developed for these applications.

Biographical Sketch
Christopher Mulligan joined Benét Laboratories in August 2000 as a Materials Engineer. He obtained a Ph.D. in Materials Science and Engineering from Rensselaer Polytechnic Institute in 2009. His work focuses on the development of deposition techniques and materials for armament systems. His areas of expertise include thin film and coating deposition/characterization, tribology, metallurgy of films and coatings, and vacuum system design. His areas of research include thin films/coatings technology, nanostructured and nanocomposite material systems, thermomechanical/thermochemical behavior of materials, and tribology.

In addition to his position at Benét Laboratories, Dr. Mulligan is a Visiting Scholar at Rensselaer Polytechnic Institute and member of ASM International and the American Vacuum Society. He has over 60 technical publications and several patents pending.
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