Materials Reliability & Performance Group (MR&PG)

- Professors - G. R. Odette and G. E. Lucas
- Four PhD level scientific research staff (one search, another coming to fill an open positions and one more just approved)
- Average of one to two visiting scientists over the last several years but currently none.
- Four grad students
- Two full time and two part time technical staff.
- Extensive experimental and computational capabilities including common UCSB laboratories and specialized MR&PG facilities.
- Ties to strong and broad UCSB programs in advanced structural materials. Housed in top ranked Materials Department and Mechanical and Environmental Engineering Department with a leading program in the mechanics of materials.
- Very extensive network of national and international collaborations.

Research Themes

- Accurate performance predictions and assessment of structural materials used for long term service in hostile environments (high temperature and stress, hydrogen, intense radiation fields,…).
- Development of advanced materials with superior performance including structural alloys, intermetallics and high performance composites.
- Built on a longstanding MR&PG commitment to an integrated materials science-mechanics based approach to solving practical materials and structural engineering problems set in UCSB's unique multidisciplinary research environment.
- The complementarity and commonality benefits of a cross-cutting, collaborative approach leads to tremendous amount of leveraging.

Research Approach

- Roadmapping - integration of people, tools and research strategy to answer questions and solve real problems.
- Experiments and models of microstructural-microchemical evolutions in long-term service using state-of-the-art simulation and modeling tools closely integrated with a broad range of characterization tools.
- Experiments and models of relations of microstructure to deformation and fracture properties, exploiting automated small specimen testing.
- Large scale experiments on the effects of metallurgical and environmental variable (synergisms-variable combinations).
- Physically based statistical correlation of engineering data bases.
- Relations of basic deformation and fracture properties to engineering properties and structural assessment methods.

Projects

- *US NRC*: fundamental integrated experimental and theoretical studies of irradiation embrittlement of RPV steels -- primary defect production, nanostructural evolution, basic structure constitutive property relations and fracture micro and macro-mechanics. Provides predictive models, support for engineering judgements, help to avoid technical surprises and advanced structural integrity assessment methods.
- *Other RPV*: CRIEPI, KAERI, British Energy and EDF.
- *NSF-UCSB MRL*: High temperature-high performance intermetallic composites; micro-mechanics of ductile phase toughening, thermal stability of high temperature properties of microlaminates - recently completed.
- *Unfunded Collaborations*: LLNL, ORNL, ANL, EDF, Mol, Tohoku U, ANL, UM, MPA, AEA, NIST,..

Projects

- *DOE Fusion*: Previously focussed on deformation and fracture mechanisms including irradiation effects models and engineering assessment methods for structural alloys. Recently expanded to broader set of topics, including multiscale modeling, advanced alloys, microstructure and mechanism studies, high temperature properties and helium effects.
- Extensive national and international collaborations:
  - NRG Petten - irradiation studies of deformation and fracture
  - PSI/EPFL - Master Curve (Irradiation) Experiment (MACE) and spallation proton studies on helium effects on fracture
  - Tohoku University - small specimen methods and dose rate effects studies
  - US-JAERI and US-MEXT within US FMS Program

Facilities – UCSB Common Laboratories

- Microscopy Lab-electron and probe (modern TEM,SEM including FE instruments, SIMS, Scanning auger, GIF, Kikuchi mapping, AFM and other scanning probe)
- X-Ray and Analytical (modern x-ray instruments including high temperature capability, good analytical chemistry)
- Mechanical Testing (complete range of fracture, fatigue, creep including many special capabilities)
- Materials Processing (broad capabilities for attriding, alloy melting, rapid solidification, coating and deposition, HIP and hot forging consolidation, high temperature processing/ sintering,..)

Facilities – MR&PG

- Computerized fatigue, static (MTS) and dynamic (drop tower) deformation and fracture with special instrumentation including methods for small specimen testing, acoustic emission, optical crack monitoring.
- Confocal microscopy and integrated image analysis fracture reconstruction computational system
- Automated tensile test system
- 3-D optical and SEM imaging systems for in situ deformation studies
- Instrumented creep frames
- Various types of microhardness including an automated system and indentation pile-up imaging
- Resistivity-Seebeck coefficient solute redistribution spectrometer, SANS (mostly done at NIST) and various collaborations ASAXS(APS), PAS (LLNL), APT (ORNL),...

UCSB Activities and Contributions to Reactor Structural Materials

1970's

- Early studies of the energy dependence of neutron radiation damage.
- Developed displacement -defect production cross section model model basis for the SPECTER Code (Greenwood).
- Early microstructural evolution models and data analysis of helium-displacement damage interactions and their effects on swelling and microstructure.

1980's

- First physical models of irradiated microstructure-property relations for hardening, ductility, creep rupture (including effects of helium) and toughness.
- Developed a comprehensive microstructural evolution model with emphasis on dislocations and swelling and helium-displacement-precipitate interactions MICROEV (Stoller).
- Proposed isotope tailoring (^{58}Ni, ^{59}Ni) and other innovative approaches to simulating helium effects.
- Pioneered small specimen techniques for deformation and fracture - ball indentation, shear punch, minicharpy, early fracture toughness…
- Identified dominant mechanisms and developed first physical models and of embrittlement of RPV steels and initiated comprehensive single variable experiments, mechanistic studies and advanced embrittlement modeling.

UCSB Activities and Contributions to Reactor Structural Materials

1990's

- Proposed and developed MC-Shift Method for integrity assessment of fusion structures applied to FM steels and vanadium alloys - now is basis for national and international UCSB-(PSI and UCSB-NRG Petten) collaborations and most recently forms a core element of two US-Japan collaborations.
- Continued development of innovative advanced small specimen mechanical test methods and test automation (Yamamoto, Spatig, He, Santos).
- Developed advanced macro-micromechanical models of cleavage fracture in the transition accounting for size, loading rate and irradiation changes in constitutive properties (He).
- Developed advanced experimental techniques such as CM/FR and large scale 3D deformation-strain mapping for deformation and fracture studies (Edsinger, Donahue, He).
- Applied micromechanical models and experimental techniques to established mechanisms and toughness models for $K_{eff}(T)$ in unirradiated and irradiated V-4Cr-4Ti and F82H (Edsinger, Spatig, Yamamoto, Donahue).
- Developed universal MC shape model and an experimental approach to testing underlying hypothesis (Hriberknik).

UCSB Activities and Contributions to Reactor Structural Materials

1990's RPV

- In support of building physical models, designed and carried out a large scale irradiation (IVAR) and annealing program to characterize the effects key variables (composition, heat-treatment, temperature, flux, fluence,….) on embrittlement (both yield stress and limited fracture toughness) as well as understanding of the underlying microstructural micromechanical processes. Automated small specimen testing enables large matrices and the experiment will eventually involve collecting more than 8000 data points.
- Used unique combinations of characterization tools (T_i-PIA, SANS and T-SANS, ASAXS, PAS, APT, FEGSTEM ….) to help identify nanofeatures in irradiated RPV steels (Mader, Wirth, Alinger and many collaborations ORNL, LLNL, AEA-Harwell, MPA, ANL, UM).
- Developed atomistic and thermokinetic models of: a) SIA and SIA cluster character and dynamics (MD); b) cascade aging and vacancy complex formation from ps to gs (KLMC), and c) chemically/structurally complex Cu-Mn-Ni nanoprecitiates (LMC and MFTD) and d) overall defect cluster evolutions (MSK-RT). Proposed the computational microscope (Chao, Mader, Wirth).
- Developed new models of strengthening superposition and fracture micromechanics (Tedeski, He).
- Resulted in new NRC embrittlment and annealing models. Now Leading US activity to build an integrated multiscale-multiphysics model of embrittlement in framework of the international project REVE (Europe, US, Japan) on a virtual materials test reactor.

UCSB Activities and Contributions to Reactor Structural Materials

1990's

- Proposed similar integrated experimental-modeling approach to developing advanced materials for fusion (FESAC panel, integrated modeling-experiment… whitepaper, program follow-up) and other substantive programmatic contributions like editorship of ICFRM-9.

2000 and future

- Continuation of many ongoing activities listed above.
- Developing a unified multiscale-multiphysics model of deformation and fracture in bcc alloys including the effects of irradiation and experimental verification and dislocation dynamics modeling (He, Hribernick, Ghoniem and Rathbun).
- Major role in the integrated scientific design of multipurpose experiments and test matrices for US-Japan (JAERI and MEXT) collaborations, lead in innovative experiments (e.g., MC, millifracture and composite ^{54}Fe fracture specimen studies) and active participation in a wide range of post irradiation research on properties, mechanisms and microstructures (ORNL, PNNL).
- Leading US effort to develop a comprehensive multiscale-multiphysics simulation code for RPV embrittlement as part of the international (US, Europe and Japan) REVE project - extend to fusion applications and further development (experiments and modeling) of the computational microscope (Stoller, Wirth, Miller).

UCSB Activities and Contributions to Reactor Structural Materials

2000 and future

- Development of advanced NCF alloys with emphasis on property optimization, nanodispersoid physics, alternative processing paths (HIP, ..), functional graded/layered systems (Alinger, Levi)
- Experiments and modeling studies of helium effects with emphasis on transport, trapping and developing integrated models of high temperature deformation and fracture properties (Ghoniem, Wirth, Kurtz, Stoller)
- Advanced materials by design modeling intitiative (Ghoniem,...)
- Contribute ideas, innovation and in-depth expertise to FMS program

Other Pertinent UCSB MR&PG Activities

- Intermetallic-ductile phase toughened composites (particle reinforced and microlaminates) including comprehensive models micromechanics of strength and toughness (bridging and constrained deformation) and the thermal stability of microlaminates. Developed strength-toughness simulation codes and design rules. (Heathcote, Ludtke, Chao and others funded by DARPA-URI, P&W, Airforce-GE, NSF).
- Hydrogen attack experiments and models of the kinetics of high pressure CH_4 grain boundary cavity nucleation and growth (P_{H2}, T and alloy composition, microstructure and thermodynamics) and corresponding consequences to mechanical properties (Chao, Hanson funded by DOE Fossil Energy).
- Integrated multi-method approaches to in-service structural integrity and residual lifetime assessments including quasi non-destructive examination and microbiopsy techniques (connecting roadmap).