Anchored in Tradition –
Soaring with Innovation:

Research in Manufacturing and Engineering Design

at UW Mechanical Engineering

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Department of Mechanical Engineering

August 16, 2006

Overview

- Research in manufacturing and engineering design
  - Emerging areas
    - Micro/Nano Manufacturing
    - Biomedical Manufacturing
- Summary

Superplastic Forming of Friction Stir Welded (FSW) Titanium Joints

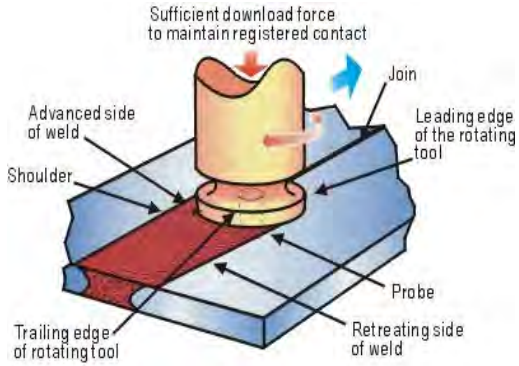
Prof. Mamidala Ramulu

Objective:

To develop a FSW/SPF process for Titanium Alloy.

Challenge:

- Controlling the geometry, optimizing FSW conditions
- Surface and sub-surface integrity
- Minimizing defect



Current Status:

- Titanium is weldable by FSW
- FSW joint Titanium was successfully superplastically formed

USC Sample #1394 SR FSW Base Material (Left) –Weld (Right) Transition Line Microstructure (50x Magnification)

USC Sample #1498 FSW SR Base Material (Right)-Weld (Left) Transition Line Microstructure (50x Magnification)

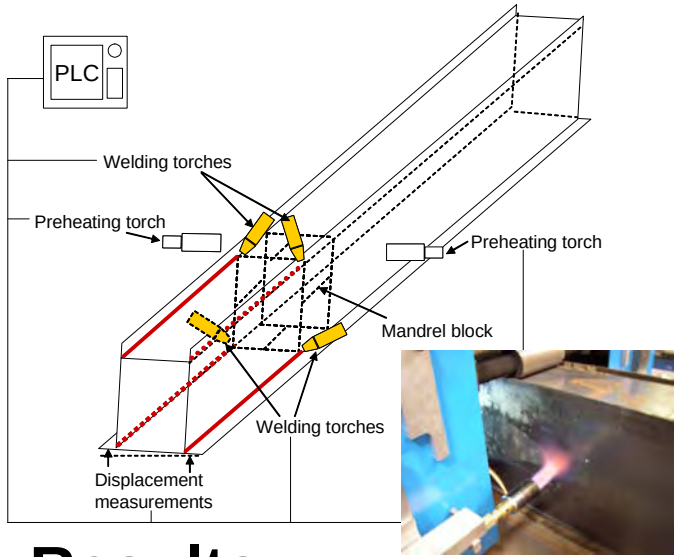
Funding: The Boeing Company

Dynamic Thermal Tensioning to Control Welding Induced Distortion

Prof. Wei Li

Objective:

To control welding induced distortion caused by production variation.

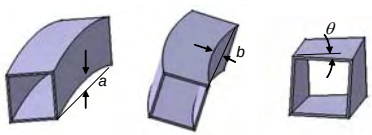


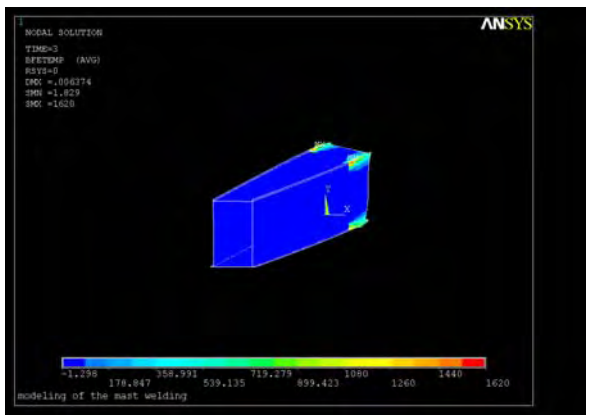
Challenges:

- Large structure, tight tolerance
- Coupled thermal mechanical material behavior
- Long time-delay

Genie Lift

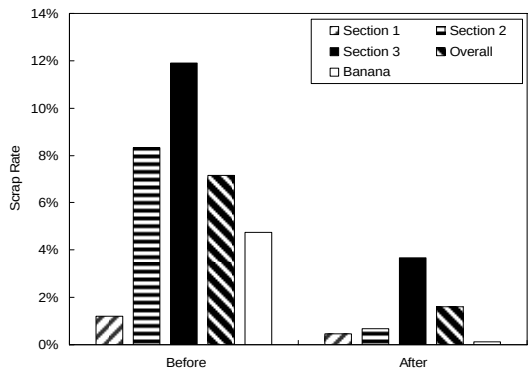
Welding induced distortion





Results:

- Scrap rate from 7% to 1%
- Millions of dollars saved



Funding: Genie Industries, Redmond, WA

A Unified Algorithm to Predict Vibration of Rotating Flexible Structures

Prof. I. Y. (Steve) Shen

Rotorcraft

Turbine Engines

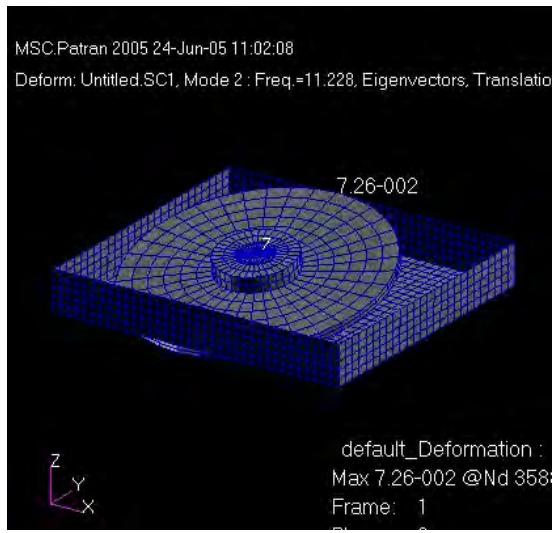
Funding: NSF, ARO

Challenges:

- No algorithms are available to predict vibration of rotating machines with arbitrary geometry.
- Design simulations rely on special software based on specific geometry.
- Physics of rotating machines remains largely unclear.

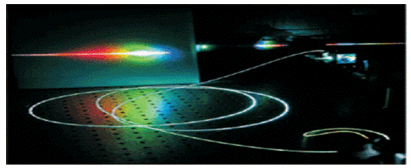
Achievements:

- Developed algorithms to predict response for arbitrary geometry.
- Filed a patent to protect the algorithm.
- Transferring technology to software developers.



Manufacture of Polymer Photonic Crystal Fiber



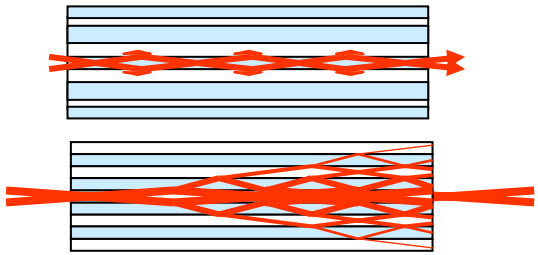


Prof. Ann Mescher

Polymer preform drawn to photonic crystal fiber (PCF).

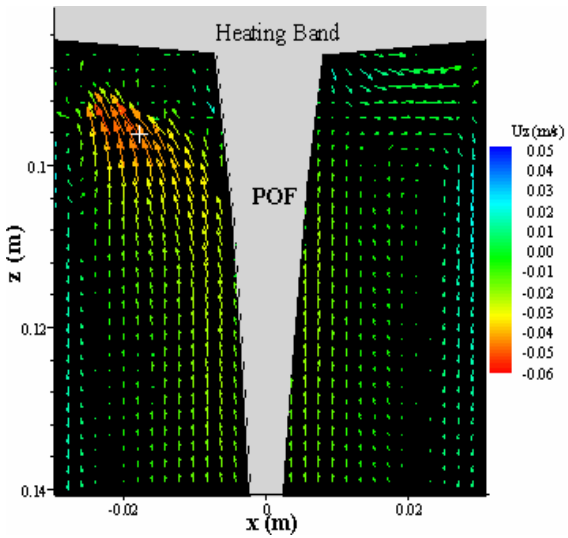
Objectives:

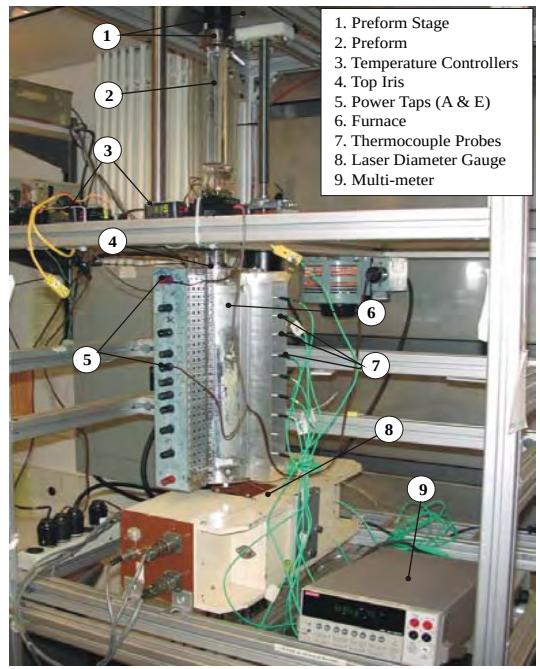
- Incorporate non-linear organics.
- Tailor PCF for highly non-linear behavior.
- Hole size, pitch controlled to 1-2%.



Challenges:

- Low processing temperatures.
- Convection's role.
- Steady/unsteady flow.
- Heat transfer effect on PCF dimensions.





Draw Tower Facility

Applications:

Wavelength converters, high speed light modulation, super-continuum generation.

Funding: NSF, STC/MDITR

Microcellular Plastics Extrusion

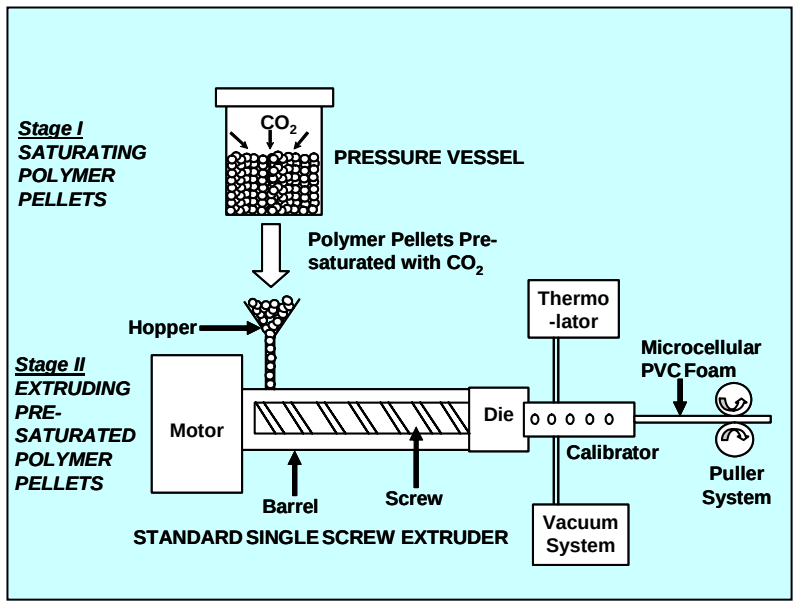
Profs. Vipin Kumar and Wei Li

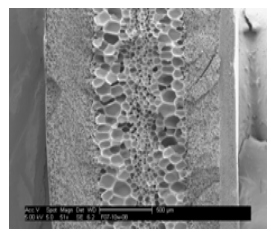
Objective:

To develop a continuous microcellular extrusion process for environmentally benign plastics: Recycled PET and corn-based PLA

Challenges:

- Short gas diffusion time
- Fast bubble nucleation
- Control of bubble growth





Funding:
to be funded by NSF

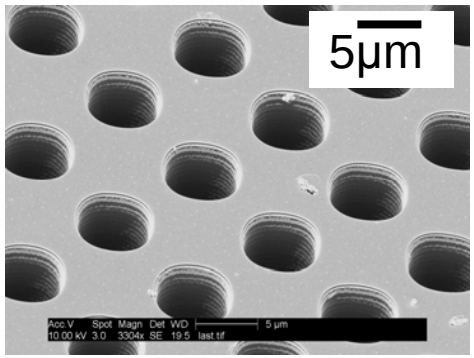
Emerging Area 1: Micro/Nano Manufacturing

Fabrication of Micro/Nanoscale Structures

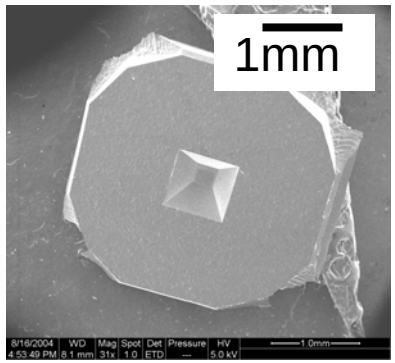
Prof. Jae Chung

Objective:

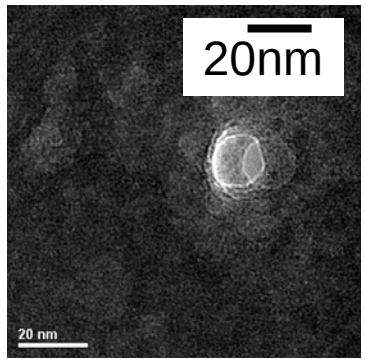
To fabricate mass-producible micro/nano structures such as gaps, pores, channels, and membranes



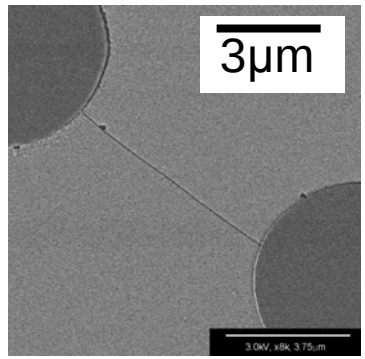
Array of micropores



Substrate for transmission electron micrscope (TEM)



Array of nanopores (18nm in diameter)



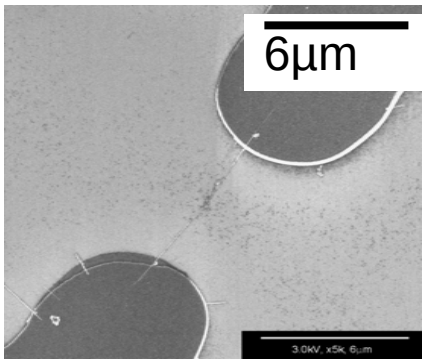
Nanoscale gap or channel (23nm width)

Molecular Assembly

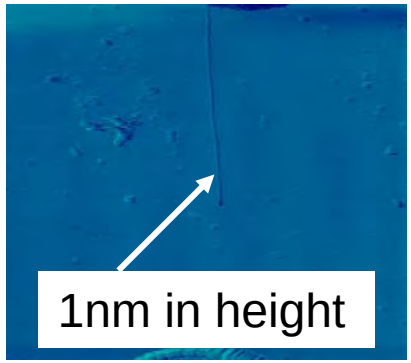
Prof. Jae Chung

Objective:

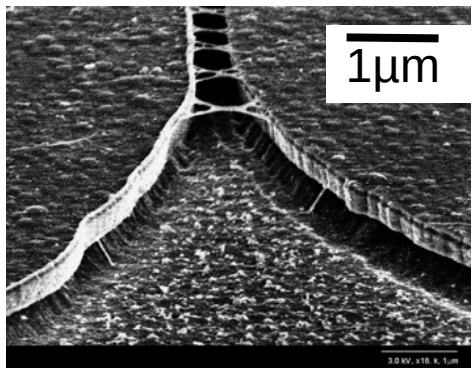
To develop wafer scale assembly of nano/bio materials with an extremely high packing density (for example, 100 molecules/μm)



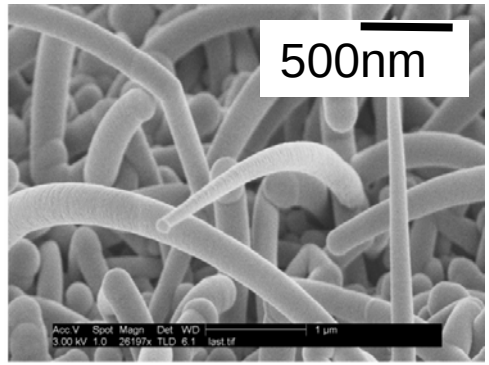
A multi-walled carbon nanotube



Single-strand λ-DNA



Single walled carbon nanotubes



Silicon nanowires (support of WTC)

Applications:

- Sensing platform for bio/chemical species
- Nanoelectronic transistors
- DNA analysis

Emerging Area 2: Biomedical Manufacturing

Patient-Specific Manufacturing (PSM)

Profs. Duane Storti, Mark Ganter
Randy Ching, Rhonda Anderson

Objective:

To rapidly fabricate patient-specific parts

Current Status:

- Accurate models (CAD models and physical prototypes) for pre-operative planning created quickly/economically from medical scan data
- Provisional patent submitted; pursuing commercialization with Tech Transfer
- Clinical trials underway (TGIF funding)
- In the works: Bio-compatible custom implants

Ex One gold alloy copings on their corresponding dies (impression models)

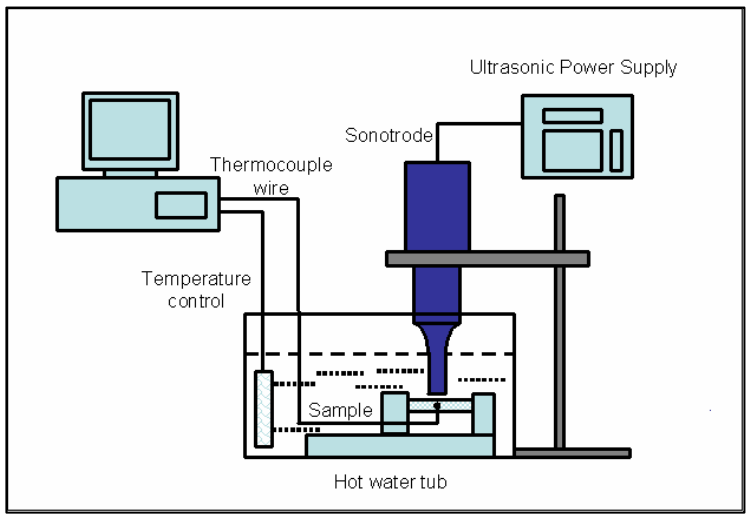
Funding: NSF-STTR, TGIF

Solvent-free Process for Tissue Engineering Scaffolds

Profs. Wei Li and Vipin Kumar

Objective:

To develop a solvent-free processing technique for fabrication of biodegradable porous polymers with interconnected pores



Approach:

Solid state foaming and ultrasonic cavitation

Results:

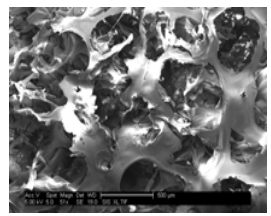
Original foam sample

(Diameter of the sample is 20 mm, pore size 200-300 um)

Foam sample after ultrasonic processing

Top

Bottom



SEM

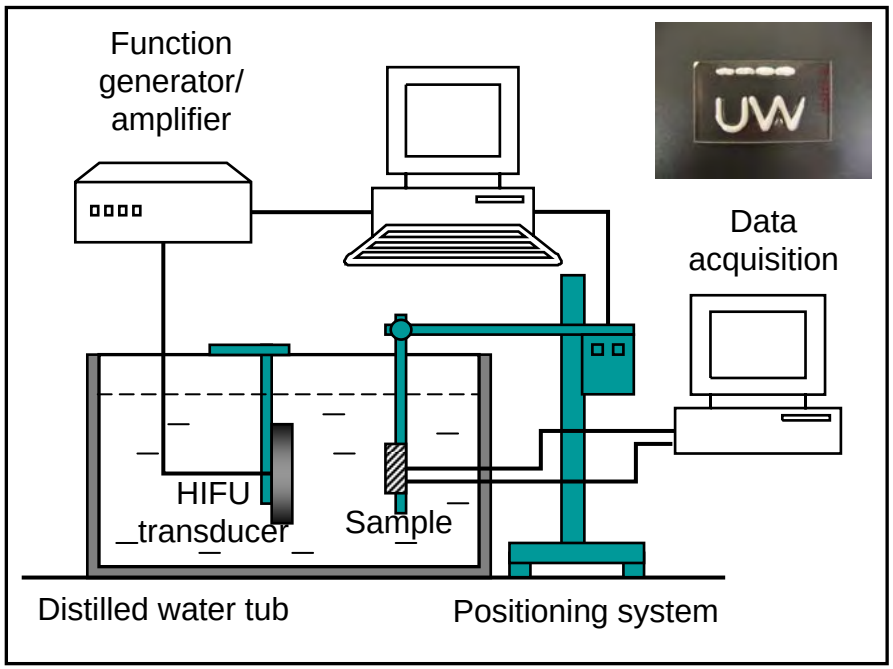
Funding: NSF

Selective Ultrasonic Foaming for Lab-on-a-Chip and Animal-on-a-Chip Devices

Prof. Wei Li

Objective:

To develop lab-on-a-chip and animal-on-a-chip devices using the selective ultrasonic foaming process.

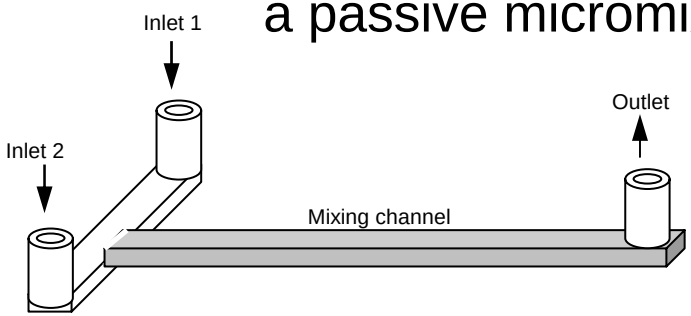


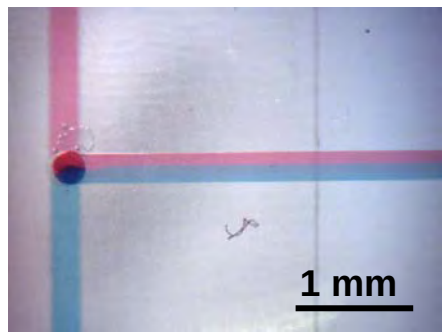
Approach:

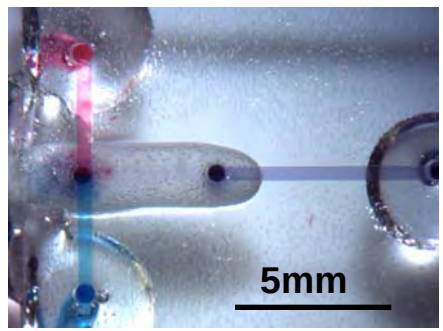
Creating open cell porous structure with controlled pore size at selected locations.

Example:

a passive micromixer







Funding: NSF

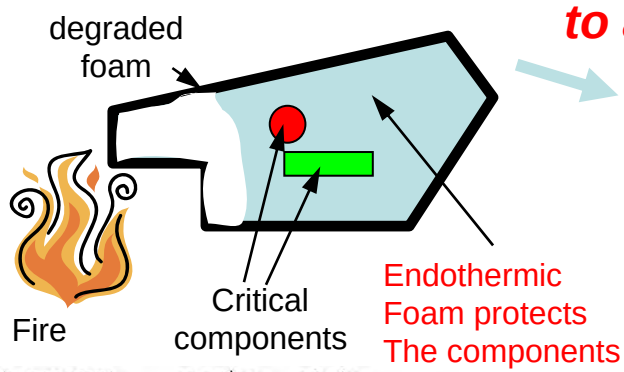
Other Research

- Machining of composites, *Mamidala Ramulu*, NSF and Boeing
- Water jet peening, *Mamidala Ramulu*, Flow International
- Fuel cell materials selection and design for recycling, *Joyce Cooper*, DOE and NSF
- Design of a Thermal Protection System, *Ashley Emery,* NSF
- Fabrication of Nanofoam, *Vipin Kumar* and *Wei Li*, NSF
- Rapid manufacturing for autonomous aerial vehicle propulsion, *Duane Storti* and Mark Ganter, Subcontract from Powerix DoD funding underway
- Microcelluar coffee cups, *Vipin Kumar*, WTC and MicroGreen
- Cluster computing for fluids simulation and CAD, *Mark Ganter*, Intel

Design of a Thermal Protection System

An Application of Global Sensitivity, Gaussian Processes, Markov Chain Monte Carlo, and Bayesian Inference to a highly Stochastic System

Prof. A F Emery

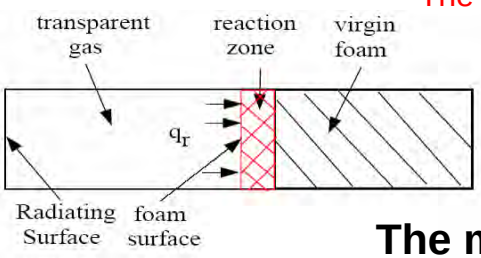


Questions:

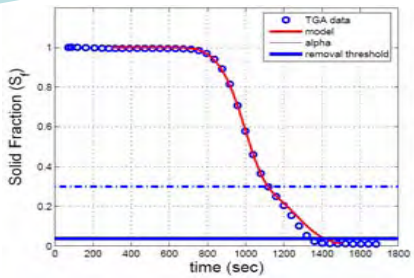
1) What is the metric of survival?
2) What is it sensitive to?
3) What does its probability look like as a function of the parameters?

The Metrics

1) Time for the reaction front to reach the component
2) Thickness of the reaction front



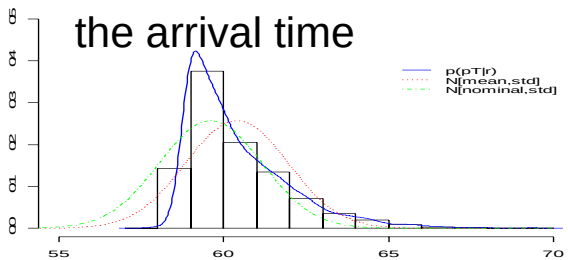
The model



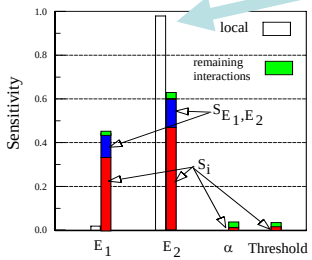
Estimate parameters from TGA Experiments using Bayesian Inference

The answer obtained by Gaussian Processes and Markov Chain Monte Carlo

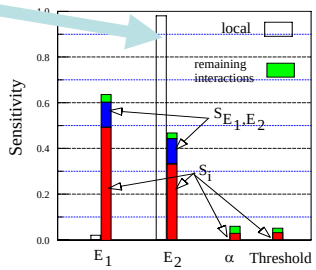
Look at the LONG tail of the arrival time



E1 and E2 affect the metrics in different ways and the usual sensitivity calculation completely misses the effect of E1



Arrival Time



Reaction Zone Thickness

Life Cycle Assessment and Fuel Cells Design

Prof. J. Cooper

- Active research topics includes:

1) Emerging technology design for the environment (forecasting the energy/materials use and emissions of mass production design and manufacturing sequences)

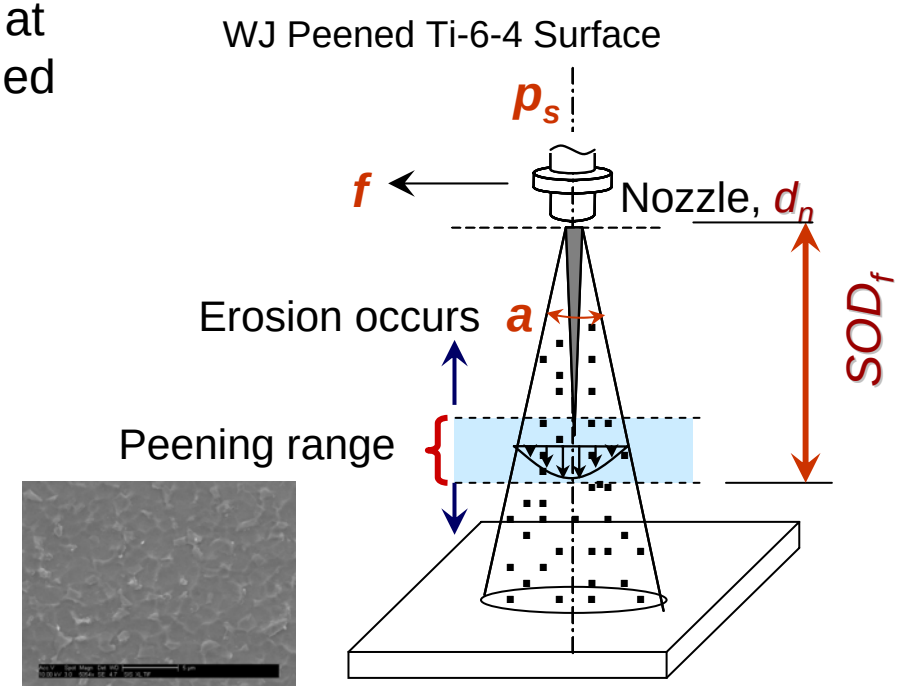
(2) Fuel cell materials selection and design for recycling

Waterjet Peening Process

Prof. M. Ramulu

- **Objective:**
  The goal of this research is to develop waterjet surface treatment processes at ultra high pressures to induce controlled surface characteristics.
- **Challenge:**
  - Controlling the droplet size, optimizing jet conditions
  - Inducing desired surface textures
  - Increasing the compressive layer depth to enhance fatigue strength
- **Current status**
  - A mathematical model was developed and verified.

Funding:
In-kind support from Flow International



Waterjet Impingement Process

Edge Trimming and Drilling Methods for Composite Materials

Prof. M. Ramulu

Objective:

Design and development of cutters for machining hard-to-cut materials, such as Polymer, Metal and Ceramic Composite Materials

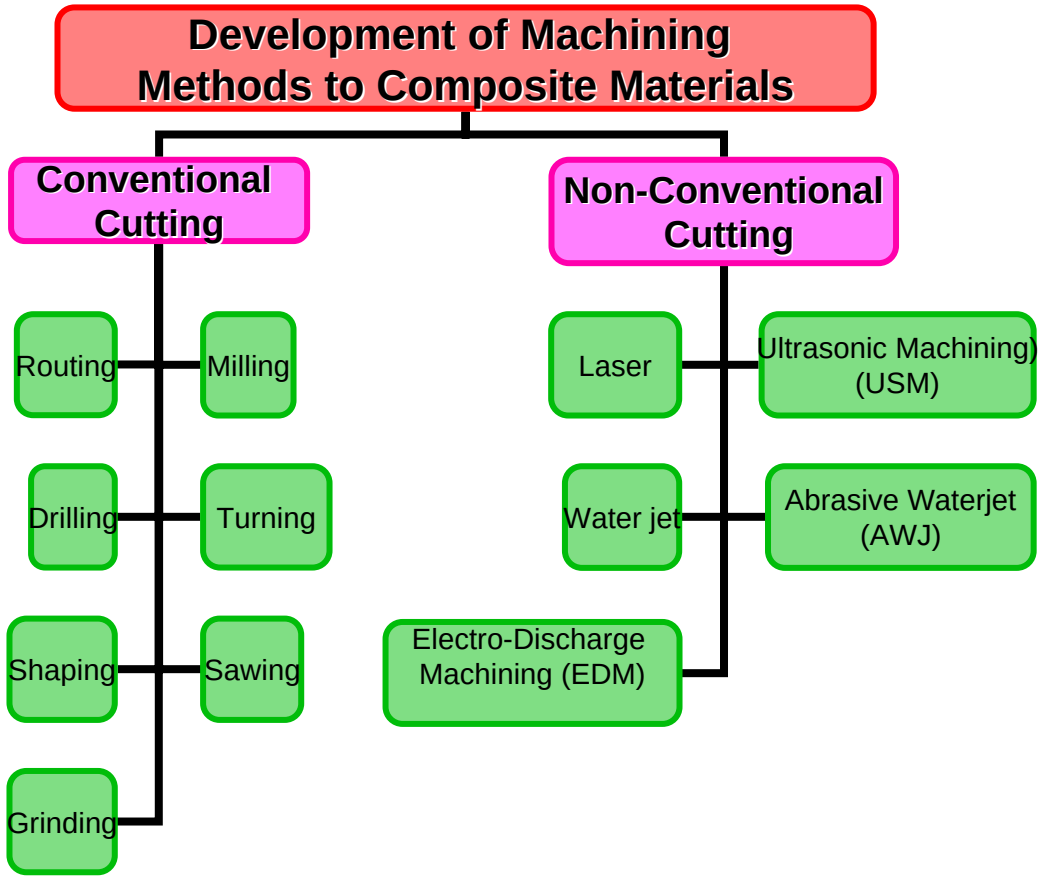
Challenges:

-Cutter design
-Surface and edge finishing quality
-Process Modeling
-Identifying the Cutting Mechanisms

Funding: The Boeing Company and other multiple of local industries

History: Work initiated in 1985, 20 years of effort.

Standing: UW is one of the leading schools in composite machining research.



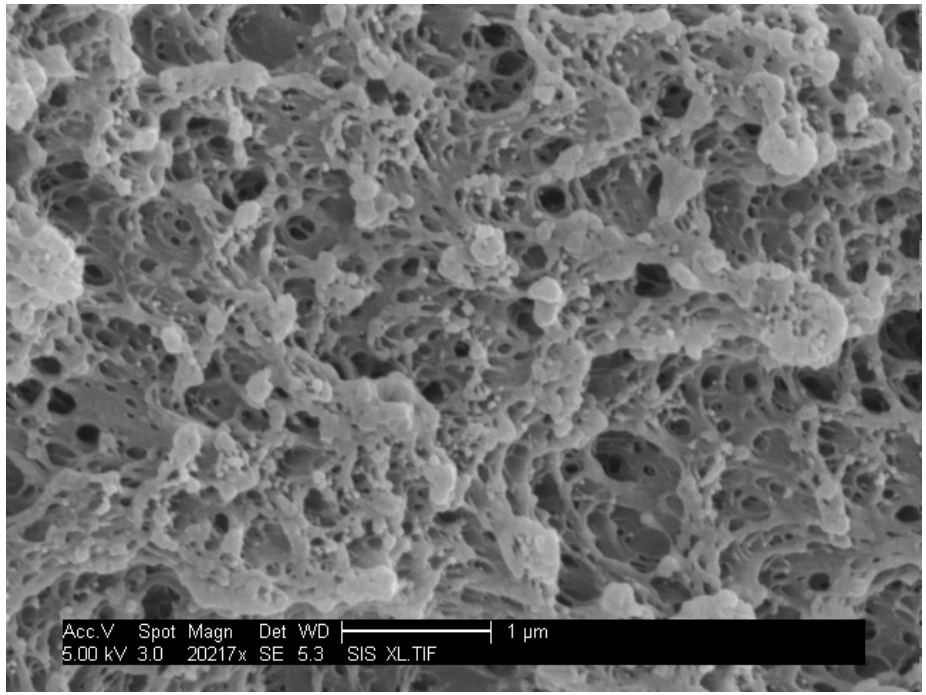
Microcellular Coffee-Cups

Prof. V. Kumar

- Recycled PET
- Service Temperature, Cycle Time, and Product Stiffness Goals Met
- Startup company launched in 2003

PEI Nanofoam

Prof. V. Kumar



Cell Size ~ 50 – 150 nm

Foam Density Reduction ~ 50%

Cell Density ~ 1.4 x 10^{14} cells/cm^3

(Unpublished Result from Kumar's Lab, May 2006)

Rapid/Additive Manufacturing

Profs. Rhonda Anderson, Randy Ching
Mark Ganter, and Duane Storti

- Active topics include:
  - Patient-specific manufacturing
  - Material systems for rapid manufacturing
  - Solid modeling systems to support new scanning/fabrication technologies
  - Autonomous vehicles
  - Cluster computing applications

Summary

- Strength
  - Anchored in tradition:
    - Strong research in manufacturing and engineering design
    - Broad expertise in materials and structures, thermal and fluids, dynamics and controls, and manufacturing and design
  - Soaring with innovation
    - Growing research in emerging areas, micro/nano manufacturing and biomedical manufacturing
    - Willing to break boundaries of traditional engineering discipline

Summary (cont'd)

- Opportunities
  - Demand for micro/nano manufacturing and biomedical manufacturing technologies
    - High performance materials, nano devices
    - Biomedical devices for drug discovery, diagnostics, and disease treatment
  - Funding agencies
    - NSF, NIH, DOD, etc.
  - Local environment
    - State initiative (Life Science Discovery Fund (SB 5581))
    - Local biotech industry
    - Potential collaboration on campus