FIRE: Facilitating Inclusive Research Experiences

NSF REU Site
Dept. of Mechanical Engineering and Materials Science
University of Pittsburgh

The list of potential projects for previous FIRE programs is below, to give an idea of potential projects for the upcoming year.

Summer 2024

1) *Solar-Powered Origami-Based Manufacturing* - Dr. Mostafa Bedewy

Motivation: Origami engineering enables creating complex 3D structures from 2D polymer sheets, and using solar radiation to directly drive this geometric change represents a promising approach for sustainable manufacturing.

Research Question: How can the spatial distribution of solar radiation be controlled to kick start directed folding at desired locations across a 2D polymer sheet?

Technical Approach: Solar radiation will be focused in order to create thermal gradients across the thickness of shape memory polymer sheets so that viscoelastic relaxation results in different degrees of shrinkage across the thickness, which leads to folding.

2) *Preventing slip-and-fall accidents through understanding of shoe-floor friction* - Dr. Tevis Jacobs

Falling accidents are the leading non-respiratory cause of visits to the ER, and many can be prevented by improvements to flooring to make them more slip-resistant.

Recent research in my group has shown novel metrics that predict slipping, but these are detected through slow and costly testing: the scientific question is whether these novel metrics can be detected through a quick optical scan.

This project involves experimental measurements on flooring using a 3D optical microscope, plus quantitative analysis of results in the context of friction experiments and analytical models.

3) *In-situ Ultrasonic Monitoring of Photopolymer 3D Printing* - Dr. Xiayun Zhao

Knowledge of material properties during photopolymer 3D printing is crucial to attaining optimum processes and high-quality parts, but current in-situ monitoring methods are costly, intrusive, and interruptive. The research question is how to develop an in-situ ultrasonic system and method that that can measure depth-resolved elastic modulus, loss factor, and degree of curing (DoC) during a novel photopolymer 3D printing process. In this project, we will design an in-situ ultrasonic sensor array on top of a lab-designed photopolymer 3D printer and develop a time-of-flight method and/or a wave dispersion method (preferred) to extract the wave velocity as well as the viscoelastic properties.

4) ***Demonstrate a New Multi-Material 3D Printing Process based on Wavelength Selective Photopolymerization (WSP)* - Dr. Xiayun Zhao**

Traditional photopolymerization-based 3D printing technologies fabricate complex parts by exposing a resin to one-wavelength light in a spatially-selective manner but require material switch-over and tedious re-alignment and cleaning to print practical multi-material components. The research question is how to harness the wavelength selective photopolymerization (WSP) mechanisms to realize rapid, continuous multi-material photopolymer-based 3D printing. In this project, we will develop a feasible material system, embody design a sample part for a chosen application (e.g., soft robot/sensor, microfluidic, circuitry) and create corresponding projection masks, and experimentally print samples with demonstrated performance.

5) ***In-situ Interferometric Monitoring of Photopolymer 3D Printing*- Dr. Xiayun Zhao**

Understanding material properties during photopolymer 3D printing is crucial to attaining optimum processes and high-quality parts, but current in-situ monitoring methods are costly, intrusive, and interruptive. The research question is how to develop an in-situ optical interferometry system and method that that can monitor voxel-resolved part-scale profiles of three dimensions, density, and DoC (degree of curing) during a novel photopolymer 3D printing process. In this project, we will design a co-axial interferometer on top of a lab-designed photopolymer 3D printer and develop a physics measurement model as well as a machine learning based sensor data analytics method.

6) ***Materials Design for Renewable Energy Technologycaptures* - Dr. Guofeng Wang**

Motivation: The commercialization of renewable energy technology, such as proton exchange membrane fuel cells, requires the innovation, design and development of high-performance yet low-cost materials.

Research Question: In this project, the functionality of electrodes and membranes of the fuel cells will be predicted and categorized in a database for design of advanced materials.

Technical Approach: The proposed research will be performed using the first-principles density functional theory calculation method and machine learning techniques.

7) ***Mechanical Testing of Menisical Repairs* - Dr. Patrick Smolinski**

Motivation: It is important to suture repair tears of the meniscus to prevent knee arthritis.
Research Question: What pattern and spacing of sutures provides the best repair.
Technical Approach: Menisci are loaded radially and tear opening gap and failure load are measured.

8) ***Advanced microstructural analysis of High Strength Low Alloy Steels (HSLA)* - Dr. C. Isaac Garcia**

High Strength Low Alloy Steels are extensively used around the world in many industrial applications. The reduction in the variability of properties represents a unique opportunity to study the effect of composition and processing.

This study will employ advanced characterization techniques (EBSD, XRD, SEM and TEM).

9) *Optimization of the microstructure and mechanical properties of Ni-Hard AM components* - Dr. C. Isaac Garcia

Motivation: The demand for higher wear resistance AM products needs a better understanding of the microstructure.

Research Question: The role of type and the volume fraction of precipitates and the matrix needs to be systematically characterized.

Technical Approach: The study will include the use of thermodynamic software, heat treatments and advanced characterization techniques.

10) *Quantum Computation for Fluid Dynamics* - Dr. Juan Jose Mendoza Arenas

Quantum computers offer an exciting potential to perform faster and higher-scale fluid dynamics simulations than classical computers. To advance in this goal, we will explore the current capabilities of different quantum computing platforms to simulate Burgers' equation. This will be done by implementing quantum imaginary time evolution in these platforms, as a way to solve the equation when transformed into the linear heat diffusion equation.

11) *High-Temperature Degradation of Materials* - Dr. Brian Gleeson

Materials for high-temperature applications, like jet engines and solar-thermal electric power systems, must resist corrosion in order to achieve extended service and avoid catastrophic failure. This project will seek to assess and understand modes of degradation relevant to what is found in aircraft turbine engines that fly in geographic locations that have relatively high particulate-matter contents (i.e., high pollution). Laboratory-scale testing of alloy coupons will be conducted, followed by detailed characterization using X-ray diffraction, and electron and optical microscopies.

12) *Additive Manufacturing of Functional Magnetic Materials* - Dr. Markus Chmielus

Functional magnetic materials like magnetocaloric materials may have a large impact on the reduction of energy usage for cooling applications. In order to use additive manufacturing to print structures that provide even more efficiency improvements, we need to explore the printability and sinterability of magnetocaloric materials. In order to explore these two aspects, we will print magnetocaloric powder using different print parameters, sinter the parts to regions with optimum density and composition, and characterize their microstructure and functionality.

13) *Stimuli-responsive gel adhesion*- Dr. Qihan Liu

Hydrogel is a smart biocompatible material that can seamlessly integrate with the human body and change its properties in response to environmental stimuli. Achieving stimuli-responsive adhesion is crucial in reversibly assembling and implanting functional hydrogel devices. This project will synthesize stimuli-responsive hydrogel and use the state-of-the-art testing setup to characterize their adhesion properties under controlled stimuli level.

14) Oscillator-Based, Neuromorphic Signal Generation - **Dr. Nikhil Bajaj**

Our brains are wired much differently from digital computers; biological neurocomputing systems like the brain have many advantages over digital systems. In this research, we aim to create oscillator electronic circuits that can act as central pattern generators for robot motion. Using models of the networks that researchers at Pitt have recently developed, we will design and build oscillator circuits that can feed their outputs to different actuators to generate motion gaits.

15) High Temperature Stability and Corrosion of Soft Magnetic Nanocomposites for Space, Electric Vehicle, and More Electric Aircraft Applications - **Dr. Paul Ohodnicki**

New magnetic materials that are stable in extreme environments are required for emerging applications in space, electric vehicles, and hybrid-electric aviation applications.
Newly developed high temperature stable soft magnetic nanocomposite alloys by the University of Pittsburgh will be investigated for their microstructure and magnetic property stability as well as their oxidation and corrosion resistance and benchmarked relative to current state-of-art alloys.
Selected alloys will be annealed at varying time intervals and temperatures and will be characterized in terms of their magnetic properties (vibrating sample magnetometry, AC permeametry), structural stability (x-ray diffraction), and oxidation resistance (optical and scanning electron microscopy).

16) Machine Learning Based Soft Magnetic Nanocomposite Alloy Design for Electric Vehicle and Power Grid Applications - **Dr. Paul Ohodnicki**

Critical needs are emerging for advanced soft magnetic alloys in applications that include inductors, transformers, and motors for applications in electric vehicles and the power grid for reduced energy losses and mitigation of global warming.
New soft magnetic nanocomposite alloys show excellent potential but are complex multicomponent systems (more than 4-5 elements) for which chemistry and thermal processing play an important role in property optimization.
Machine learning based techniques will be applied to existing and newly generated alloy property data by the team in order to classify, characterize and understand trends for the purpose of rationally designing new alloy systems with substantially improved properties.

17) Electrical and Thermal Properties of Soft Magnetic Materials for Power Electronics and Motor Applications – **Dr. Paul Ohodnicki**

The ultimate performance limitation of many advanced power electronics and motor technologies applied in demanding applications such as electric vehicles, electric power grid, and hybrid-electric aviation applications is due to the electrical and thermal performance of magnetic materials.
The project will investigate electronic and thermal properties of emerging magnetic materials including both nanocomposite alloys and ferrites, relevant for power electronics and motor applications.

New techniques for characterization of electronic and thermal properties of both metallic glass and nanocomposite ribbons as well as ferrite pellets will be developed and utilized to characterize trends in chemistry and thermal processing.

18) Melt pool and porosity variability in additive manufactured metals for aerospace applications - Dr. Albert To

Motivation: Melt pool and porosity are critical to fatigue life in additively manufactured (AM) metals, but their variation depend on local geometry, and hence pose significant challenge in qualification and certification.
Research question: What is the size distribution of melt pool and porosities in AM metals?
Technical Approach: Optical microscopy and image analysis will be utilized in this research.

19) 3D printing of refractory alloys - Dr. Wei Xiong

The manufacturing of refractory metals poses challenges for defense and civil engineering applications, attributed to their exceptionally high melting points and susceptibility to embrittlement at low temperatures. This project suggests a co-design approach involving alloy composition and additive manufacturing processes to improve the mechanical properties of 3D-printed refractory alloys, with tungsten as the primary constituent. The integrated materials computational design approach with both experiments and physics-based modeling for alloy development will be applied in this proposed research.

20) Thermal Wave method for the in-pile determination of irradiated fuel thermal diffusivity - Dr. Heng Ban

Motivation: The thermal properties of nuclear fuel change over time and these changes are hard to measure using state of the art methods

Research Question: Can we use thermal waves to measure nuclear fuel thermal properties without destroying them?

Technical approach: We are using laboratory experimentation to aid in the development of a thermal wave-based measurement method to track nuclear fuel property changes non-destructively and in-pile