Micromechanical Deformation & Characterization of Materials

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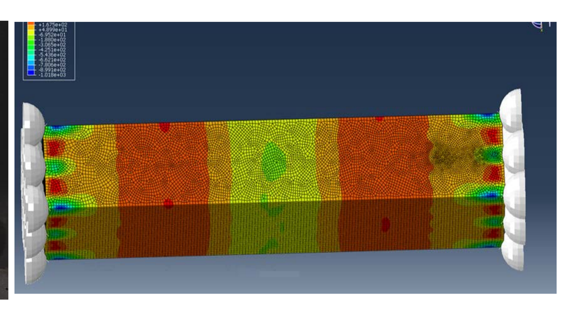
PURDUE MATERIALS ENGINEERING

The ability to characterize the mechanical properties of materials at the nanoscale has become a crucial component of the research and development in nanoscience and nanotechnologies. Such ability addresses themes relevant across a number of manufacturing and processing sectors such as semiconductor industry, life sciences, electronics and biomaterials. The global market for all types of materials characterization instrument was worth an estimated $20.3 billion in 2003. Our group works on linking the structure of a wide range of classes of materials and processing with the subsequent micromechanical behavior, including elastic, plastic, and fracture properties.

Shot Peening for Surface Enhancement

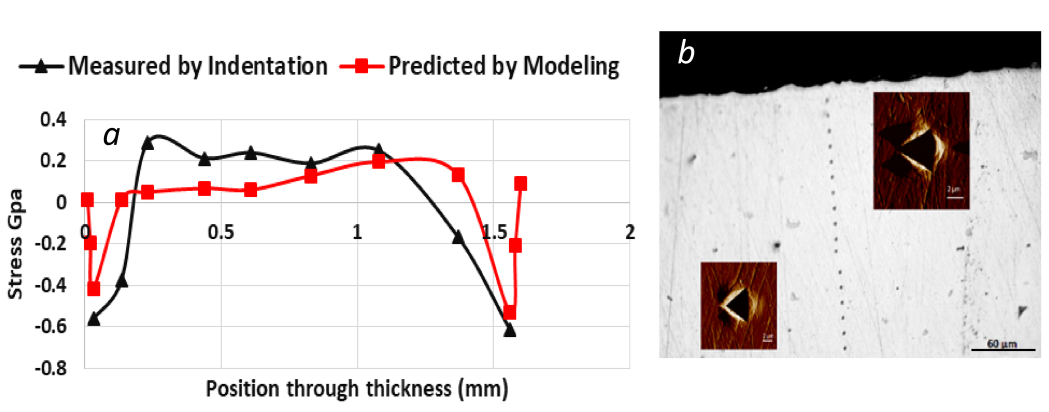
Mechanical surface treatments use cold working to develop residual stresses on the substrate or in the bulk to enhance a material's mechanical properties. Materials that are mechanically surface treated tend to have increased service lifetimes and resist wear and fatigue. Shot peening is one of the well-established methods to induce compressive residual stresses in the metallic components for the cold working purposes.

Shot peening on aircraft component to develop residual stress. (Image courtesy Wheelabrator Group.)



Multiple and double side shot peening simulation, aluminum 7050.

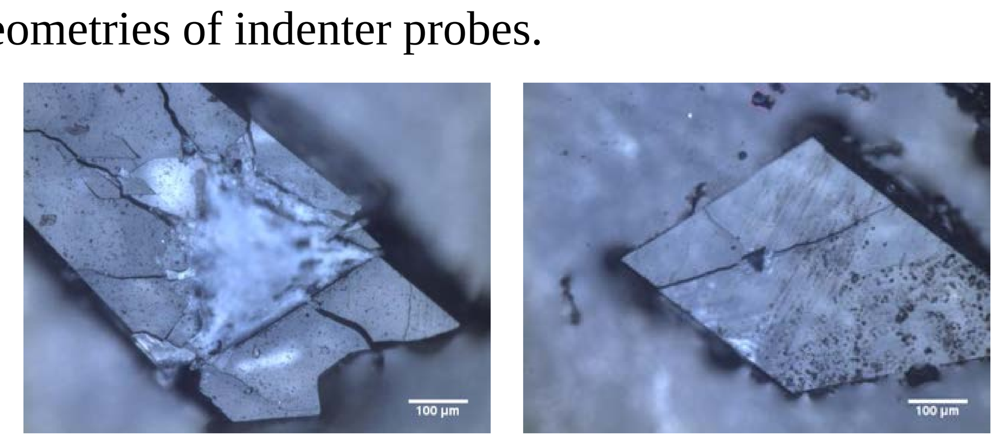
Finite element simulation and nanoindentation methods can be used to study the elastic-plastic deformation and mechanical behaviors after shot peening process to determine residual stress profile.



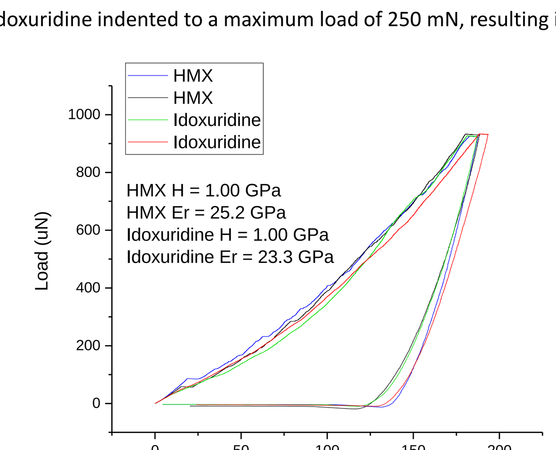
a) Nanoindentation pattern along the sample, b) nanoindentation pattern to measure residual stress indentation.

Mechanics of Energetics

Testing dangerous and expensive, so it is often desirable to have an inert "mock material" that imitates the mechanical, chemical, and thermal properties of the explosive. Nanoindentation is a useful way to study and compare mechanical properties of these crystals such as hardness and elastic modulus, as well as cracking behavior. The pharmaceutical idoxuridine is very similar to the explosive HMX in hardness and elastic modulus, with respective elastic explosive molecular crystals can be very modulus values of 23.3 GPa and 25.2 GPa and each with a hardness value of 1 GPa. Cracking behavior is being studied by analyzing the unloading portion of the load-depth curves for each material using different geometries of indenter probes.



Idoxuridine indented to a maximum load of 250 mN, resulting in fracture.



Load-depth data comparison for HMX and idoxuridine indented to a maximum load of 1000 µN, showing similar mechanical response in each material.

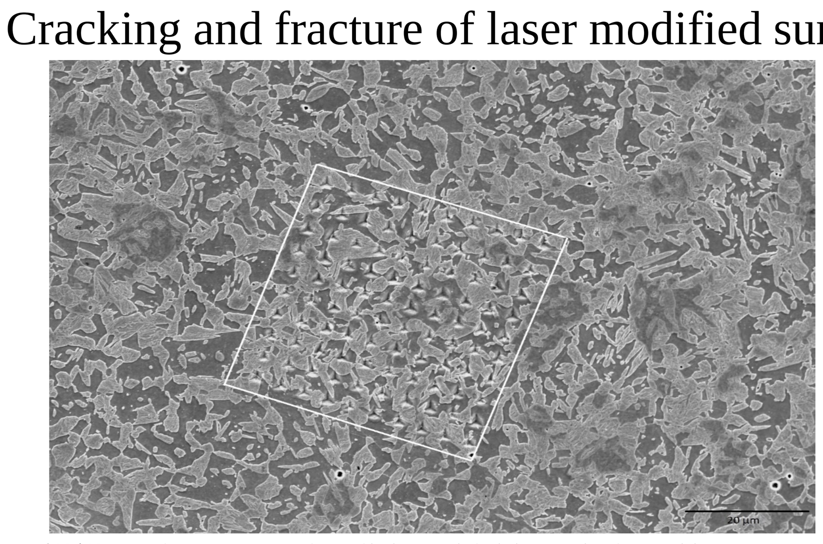
The "Why" of Small Scale Indentation Testing

Characterization of the mechanical response of materials under nanoindentation (load-displacement monitored indentation), when coupled with scanning probe microscopy can be used to test small volumes of materials that are either

(1) Small because the sample is small, or
(2) Features in the material are small (such as second phase particles).

Nanoindentation is one of the fundamental tools used within our group to explore diverse materials, either experimentally or coupled with computational modeling. Some examples of current areas of research where we are assessing materials properties and structures are

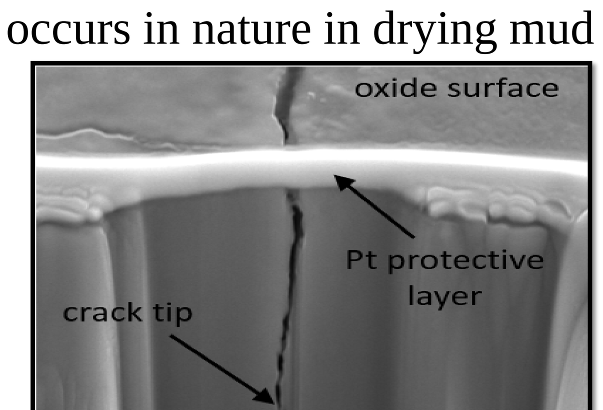
(A) Shot peened surfaces for creating fatigue resistant structures
(B) Mechanical characterization of complex nano-foams
(C) Energetic and explosive materials tested in volumes that are safe to handle
(D) Dual phase metal systems
(E) Characterize adhesion of cytotoxic nanomaterials on polymeric supports for antimicrobial filtration membranes
(F) Cracking and fracture of laser modified surfaces



SEM image of 10 *10 nanoindentation array on advanced high strength dual phase steel to distinguish between martensite and ferrite based on their mechanical properties differences.

Antimicrobial Cracked Surfaces

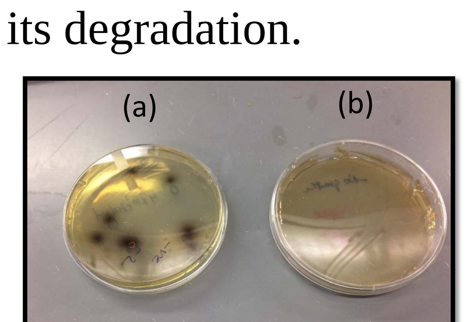
Pulsed lasers can be used to modify a surface. They interact with metallic surfaces causing repeated heating/cooling cycles, which originates a network of microscopic cracks on the surface. This phenomenon also occurs in nature in drying mud (mud-flat cracking).



Ti-6Al-4V after PL treatment. Cracks penetrate oxide film and substrate.

These cracks do not alter the mechanical properties of the remaining metal. Metallic pipelines under water are very susceptible to the attack of bacteria (bio-corrosion), which bind to the surface forming biofilms. Antimicrobial peptides (AMP) can be infused into the cracks to confer antibacterial properties to the metal surface and, in this way, avoid its degradation.

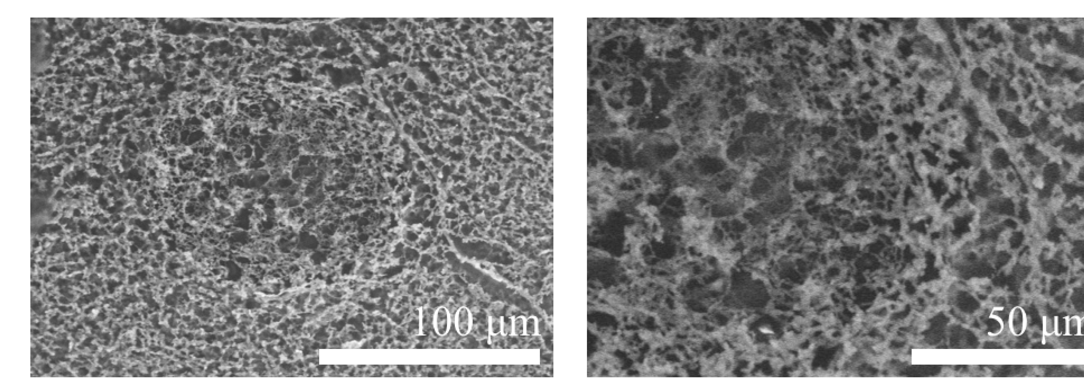
Corroded steel pipelines covered by biofilms.



(a) Bacteria grow on unprotected surface,
(b) No bacteria on surface treated with AMP.

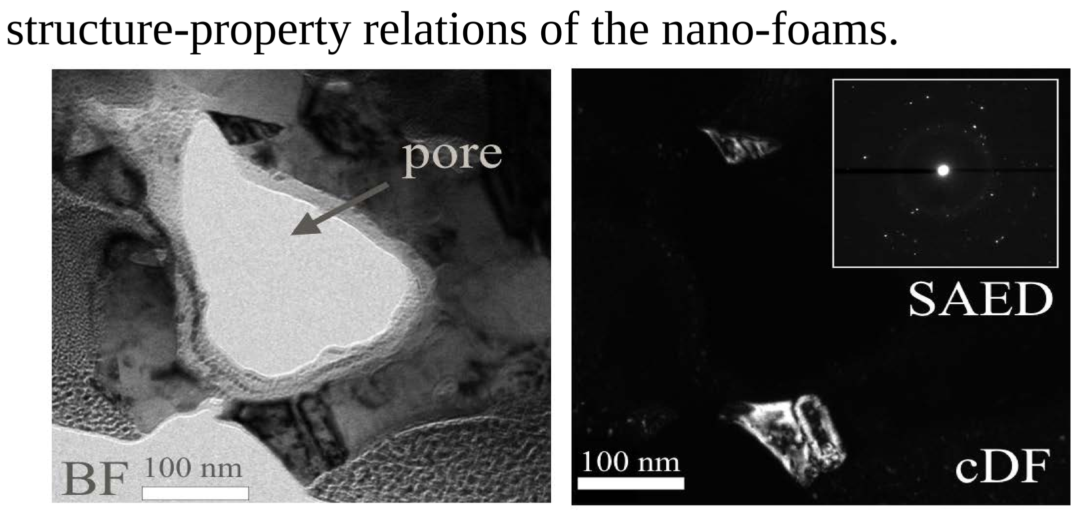
Metallic Nanofoams

Metallic nano-foam is an extremely low-density metal that has very high surface-to-bulk ratio, and have been predicted to exhibit exceptional strength to weight ratios. Using advanced structural characterization tools, we investigate fundamental structure-property relations of this nano-foams.



Indentation mark made after indenting Cu nano-foam, using cylindrical flat punch tip.
Deformation mechanism of this extremely low density material can be evaluated using nano-indentation.

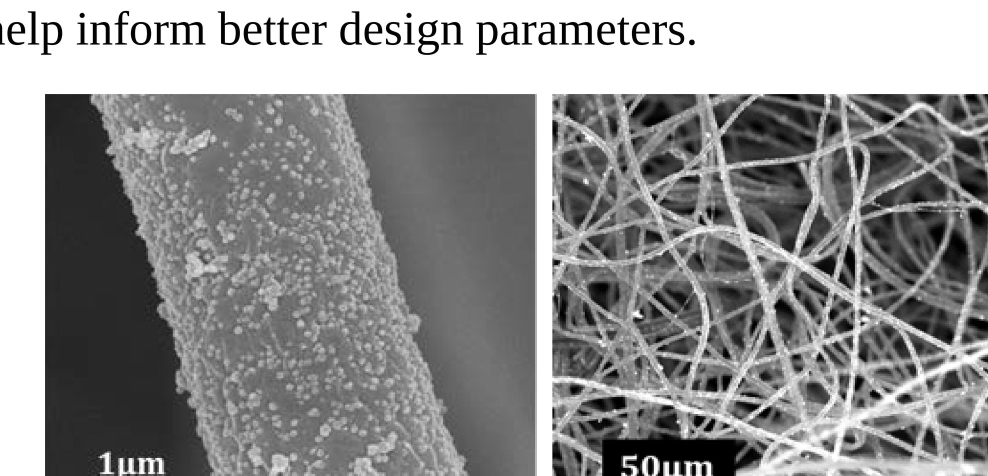
Assessment of the reliability of this exotic structural phase is crucial to developing any advanced applications. We use nanoscale mechanical testing in conjunction with accurate structural analyses to fully understand the structure-property relations of the nano-foams.



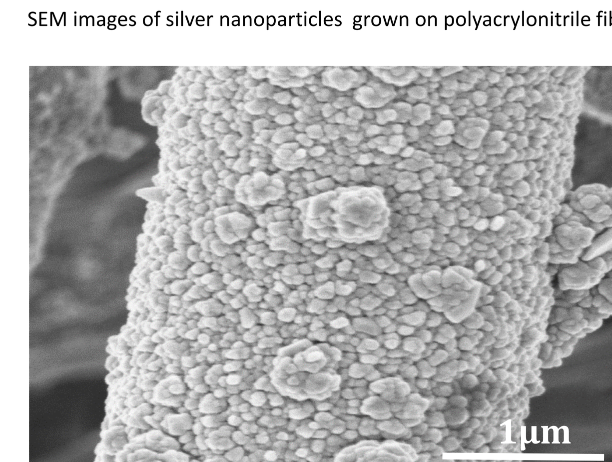
Transmission electron microscopy images of the nano-foam showing pore structure. Corresponding centered dark field (CDF) image and selected area electron diffraction (SAED) pattern show the polycrystalline nature of this metallic nano-foam.

Metal-Polymer Composites for Water Filtration Applications

Pathogenic microbes in water require clever combative techniques for prevention as well as control. Nanoscopic silver and copper are excellent antimicrobial agents with good physiological tolerance. Incorporating metallic nanoparticles on fibrous polymeric architectures creates a safe antibacterial water filtration membrane. The difference in molecular configurations of metals and polymers inevitably presents an adhesion challenge between these materials, undermining the functional application of fabricated membranes. Investigating bulk deformation behavior of metallized fibers as well as characterizing adhesion and delamination properties using surface probing functionality of the nanoindentation technique will help inform better design parameters.



SEM images of silver nanoparticles grown on polyacrylonitrile fibers.



Copper particles on polycaprolactone fiber.