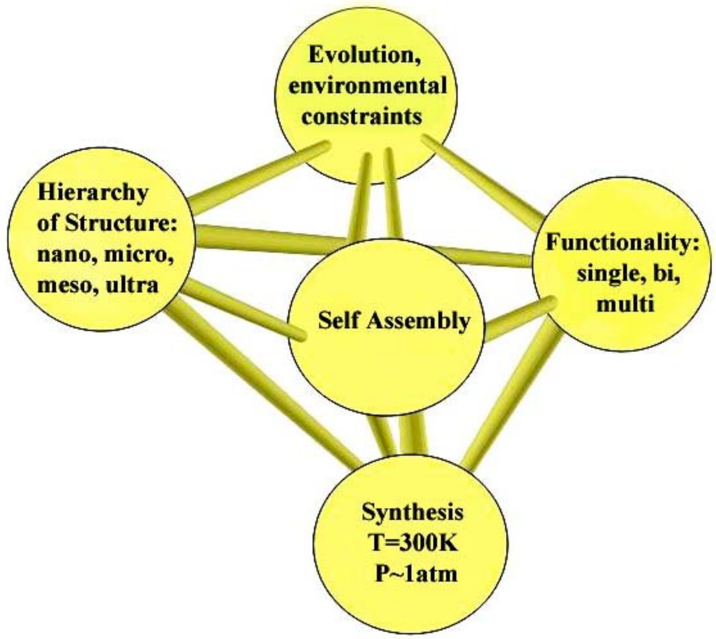
CURRENT RESEARCH

1.BIOLOGICAL MATERIALS

We are currently studying a variety of biological materials, including shells, crab exoskeleton, bird beaks and feathers, and a variety of sharp natural materials. Natural composites, comprising soft organic and hard inorganic components in a well-defined hierarchical structure give enhanced mechanical properties that are far beyond those can be achieved using the same synthetic materials with present technologies.



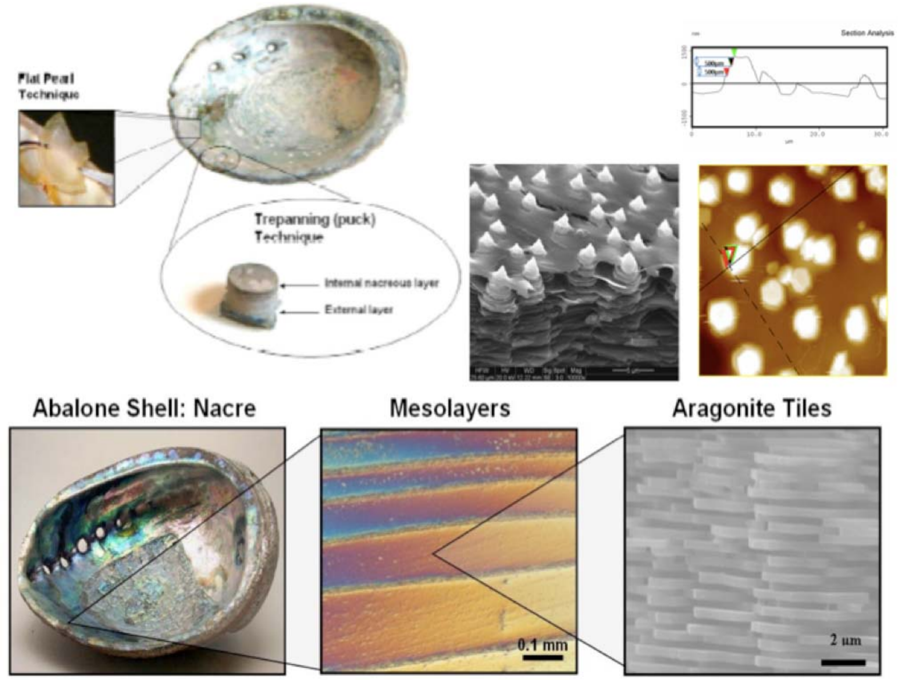
Our activities in these areas are summarized in three review articles:

- Meyers 277
- Meyers 290
- Meyers 304

The Arzt Pentahedron, shown below in modified form, provides a schematic illustration of the unique aspects of biological materials.

A. Growth and mechanical properties of Shells

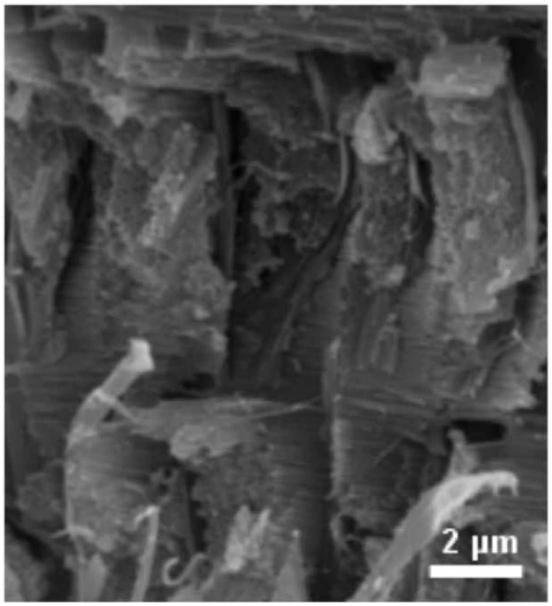
The growth of calcium carbonate intercalated with organic membranes which occurs at ambient temperature and in an aqueous environment is a complex process that gastropods learned well and that we, humans, are only starting to elucidate. These simple organisms amazing materials with incredible structural hierarchy are formed from otherwise weak constituents, often times exhibiting astounding mechanical properties. The abalone shell for example is composed of 95% inorganic calcium carbonate (chalk) and 5% organic proteins, yet has a mechanical toughness far greater than either component.

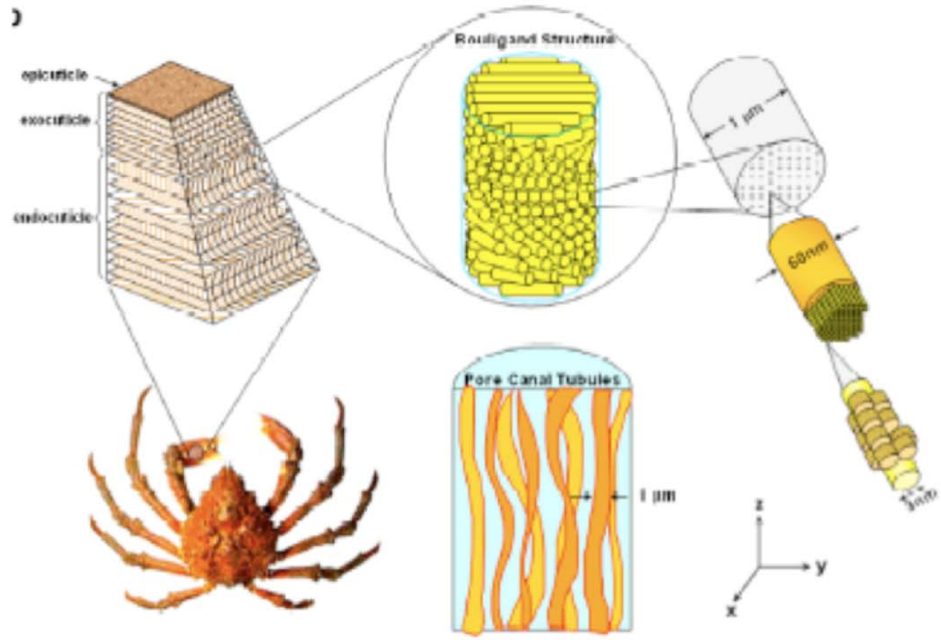


The increase in strength is a product of a highly ordered hierarchical nano, micro, and macrostructure of ceramic bricks 0.5 µm in thickness with 20 nm thick organic interlayers. We grow our shells in tanks at Scripps Institution of Oceanography . At UCSD, we study the growth, structural design, and mechanical properties of these shells with the hope of inspiring novel advances in modern materials science.

In studying the mechanical properties we have discovered that nanoscale (~50nm) pillars connecting adjacent layers of tiles play an important role in the mechanical toughness .
Meyers 211; Meyers 214; Meyers 261; Meyers 271; Meyers 289 Meyers 290 ;Meyers 291; Meyers 304

B. Exoskeletons





The exoskeleton of crabs is a complex composite consisting of highly mineralized chitin-protein fibers arranged in a twisted plywood or Bouligand pattern. There is a highly density of organic tubules in the vertical direction that stitch the structure together. We study the structure and mechanical properties of the exoskeletons of Sheep crab (Loxorhynchus grandis), Stone crab (Menippe mercenaria), and Horseshoe crab (Limulus polyphemus). These investigations on crab exoskeletons could lead to further understanding of biological composites and inspire the development of novel materials.

Meyers 303

C. Bird Beaks

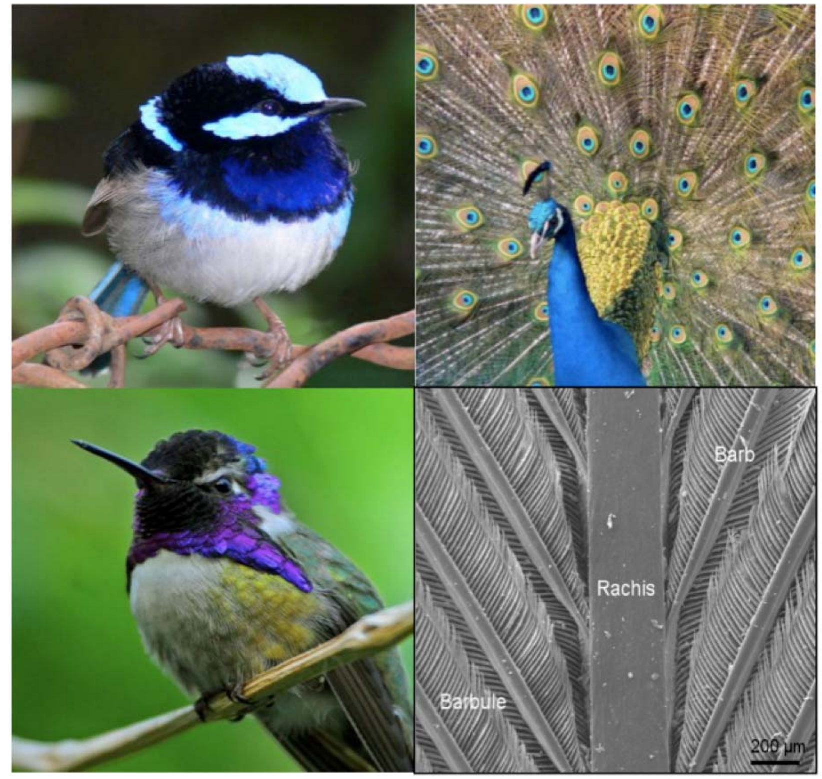
The beak of Toucan and Hornbill is exemplary of sandwich construction in nature. The beak consists of the ß-keratin shell and bony foam interior. Sandwich construction appears in many plants, invertebrates, and birds. However, in biological systems it has a degree of complexity not found in synthetic structures. The exterior shell is comprised of multiple layers of staggered keratin tiles. The Toucan and Hornbill foams have a closed-cell system constructed from bony struts as edges with thin membranes for faces. The sandwich structure of the beak has mechanical and structural advantages. The synergism between the keratinous exterior and the cellular core increases the resistance to buckling.

The hollow mid-section of the structure allow for rigidity to flexure and with low density. We are studying the mechanical properties and structure of the beak. The optimized sandwich construction of beak can be applied to our current industrial sandwich panels applicable to aeronautical and maritime transportation vehicles.

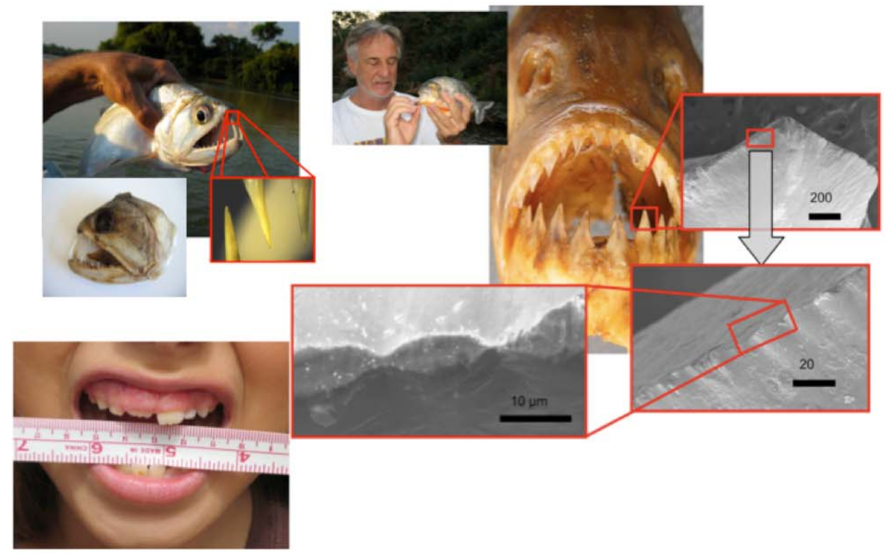
Funded by the National Science Foundation, Division of Materials Research, Biomaterials Program (Grant DMR 0510138) ;Meyers265; Meyers270

D. Bird Feathers

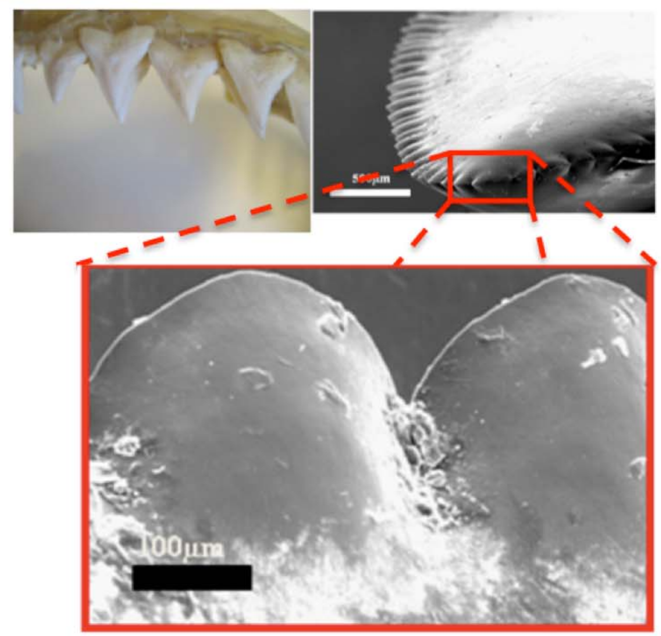
Avian materials are remarkable because they are typically relatively light in weight and/or low in density while sufficiently strong for purposes of protection or utility in feeding and foraging. Keratinous and calcareous avian materials derive strength from systems of cellular solids (foam and honeycomb structures) and embedded fibers. The purpose of these studies of avian materials is to correlate structural characteristics to mechanical properties and behavior of low density materials occurring in nature.



E. Teeth: Serrated and Smooth



We are elucidating the internal structure and overall shape of teeth in an effort to establish the synergies in the structures. Of particular interest is the presence of serrations in carnivorous animals and their absence in piscivorous teeth. We have measured the serration spacing in shark and found that it is not determined by the size of the fish, but by the mechanical prepertis of the flesh. It is interesting to note that the serrations in shark teeth are approximately equal to those in dinosaurs.



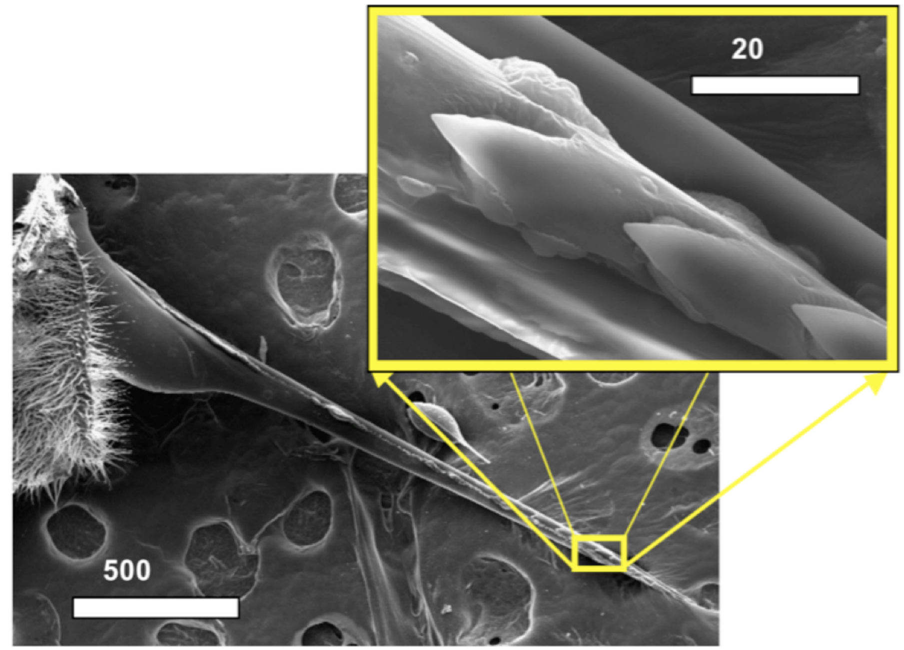
We have also studied piranha, dog fish, and rodent teeth. Rodent teeth exhibit a peculiar behavior, self sharpening, which has been biomimicked by a group of German researchers.

This research scope involves in two parts which are natural properties of teeth such as piranha teeth and the ult. The microstructure and mechanical properties of the piranha is an interesting field to investigate. Bioinspired materials fabrication based on the natural materials are also related to my study.

Meyers 305

Bee, mosand Hornet Stingers; mosquito proboscis

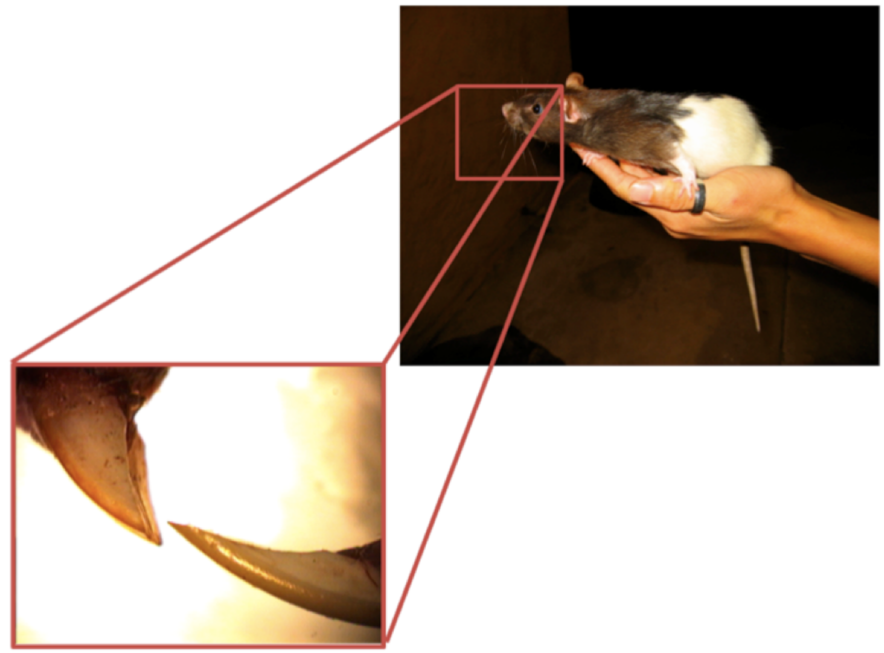
There is a great contrast between these. Bee stingers have sharp wedges that impede the stinger to be removed, once it has been used. Hornet stingers are reusable. Mosquito proboscis has a jagged knife appearance and cuts into the flesh by minimizing pain, so that the insect can complete the operation without being noticed.



Rodent Incisors

The rat and sqirel teeth as other rodents, have a unique self sharpening aspect. The softer dentine is rubbed away, exposing the harder enamel along the edges and ensuring a sharp cutting surface that is continuously maintained. Since rodent teeth continue to grow, this process is periodically implemented by the animal using a hard surface and working the teeth against it.

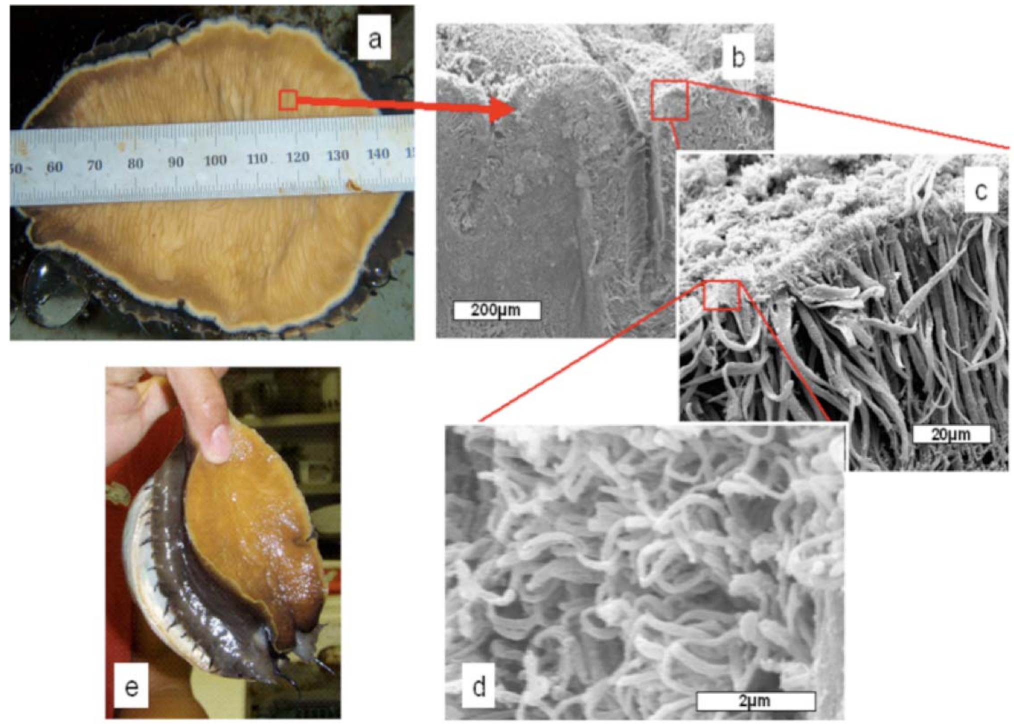
Meyers 305



F. Natural Reusable Adhesives

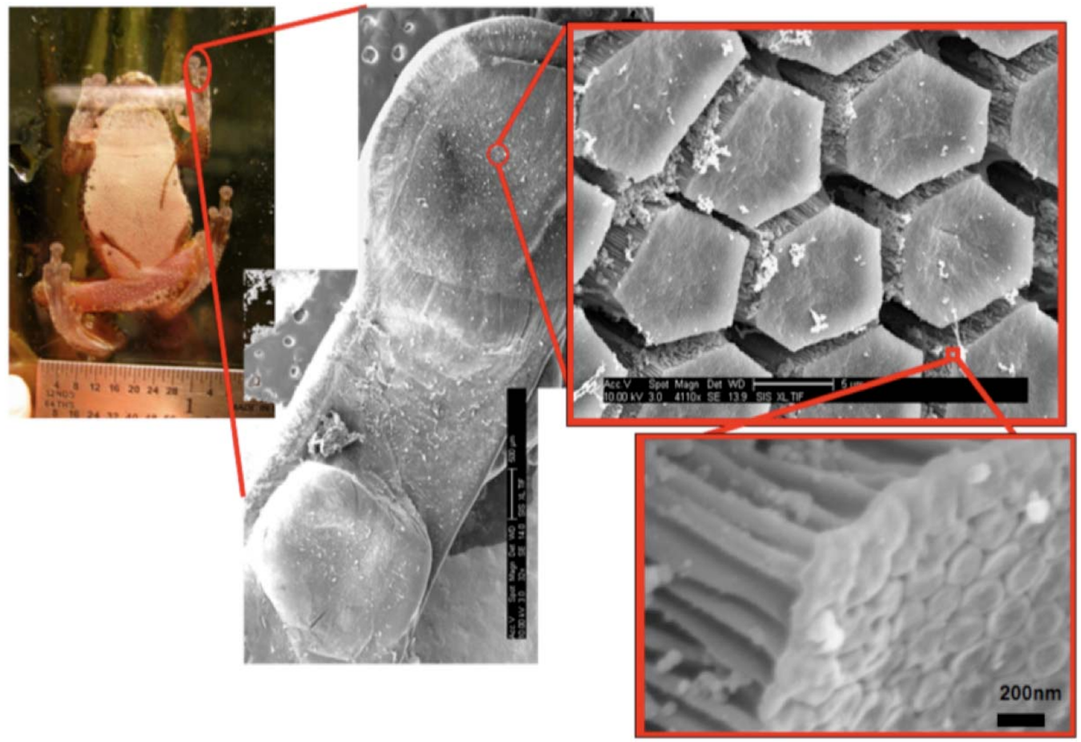
•Abalone Foot

This research provides the first evidence of a marine species, the abalone, utilizing nanofibers to exploit Van der Waals and capillary forces for the mechanism of attachment in a wet environment. Previous examples of this mechanism, i.e. the gecko, resulted in various interdisciplinary efforts to mimic these structures for dry applications. The present finding not only broadens the scope of such efforts to include wet environment applications ranging from marine engineering to biomedical sciences but also provides an example of the theoretical limit of this adhesion mechanism realized in nature. Furthermore the findings represent an evolutionary convergence of design in two unrelated species that exist in extremely dissimilar environments.



•**Brazilian Tree Frog, *Perereca***

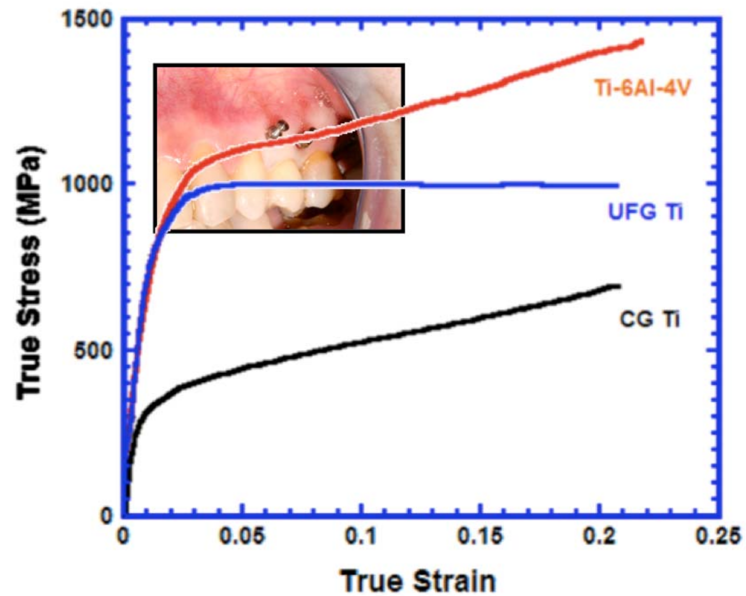
The fine microstructure of the toe pad of the Brazilian tree frog consists of hexagonal clusters of fiberous rods line the surface of the toe pad and are beleived to exploit the mechanisms of wet adhesion. By close observation of the pads, we discovered nanoscale fibers terminating in cups with~200 nm diameter. We believe that they play a role in adhesion.



G. BIOMATERIALS

•Dental Materials/Mini-implants

1.We are using ultra fine grain titanium by ECAP (Equal Channel Angular Pressing) and investigate the microstructure and mechanical properties. This "nano" titanium has higher strength than commercially pure titanium. Its strength is of the same order as that of Ti6Al4V, without the presence of deleterious elements Al and V, which can leach into the body and be a health hazard. We are working with prof. Carlos Elias, IME, Brazil, and Dr. Glaucio Serra.



2.Osseointegrated titanium mini-implants are an excellent alternative to traditional orthodontic anchorage methodologies and they are a necessity when dental elements lack in quantity or quality, when extraoral devices are impractical, or when noncompliance during treatment is likely. They are inserted into oral bone and used as anchorage devices during the orthodontic treatment. The early load and the decrease of the size of the mini-implants are necessary to simplify the methodology, but it can lead to failure during the osseointegration.

3. The Ti-6Al-4V alloy is used instead of commercially pure Ti due to its superior strength, allowing the decrease of implant size without fracture. However, the corrosion resistance is low, allowing metal ion release. We are investigating the immediately loaded mini-implant fixation and the titanium, vanadium, and aluminum ion release during the healing process.

Meyers 280; Meyers 293; Meyers 294; Meyers 284

H. DYNAMIC BEHAVIOR OF MATERIALS

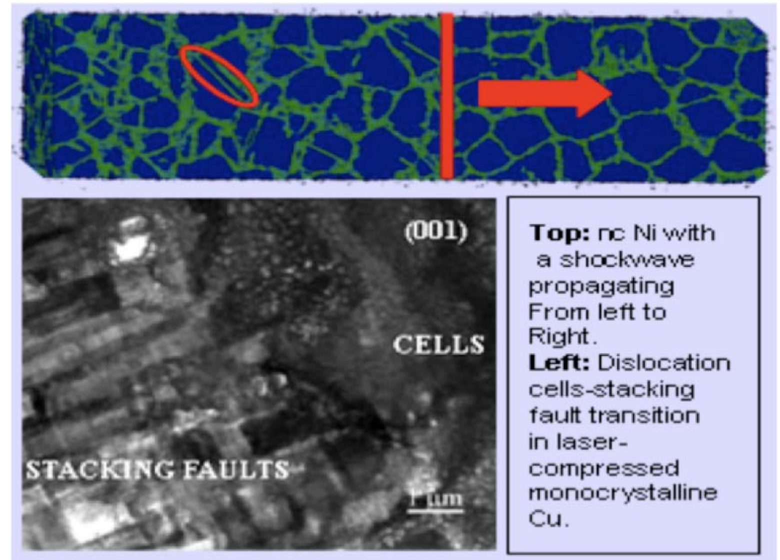
This encompasses a diversity of approaches, including lasers, gas guns, explosives, Hopkinson pressure bars. This area has been the principal theme of research of the Meyers group since 1974. Thus, it represents 35 years of uninterrupted research.

A. Shock Effects:

From Mono-crystals to nano-structured metals

The National Ignition Facility Program at Lawrence Livermore National Labs promises to advance research in ignition, high-energy-density-matter, and laser technologies. Nanocrystalline materials are being studied to determine their feasibility in solving some of the many challenging problems associated with inertial fusion confinement and target capsule design, among which are defect generation and their transitions and void collapse under extreme conditions.

Meyers 288; Meyers 298; Meyers 292.



Top: nc Ni with a shockwave propagating From left to Right. **Left:** Dislocation cells-stacking fault transition in laser-compressed monocrystalline Cu.

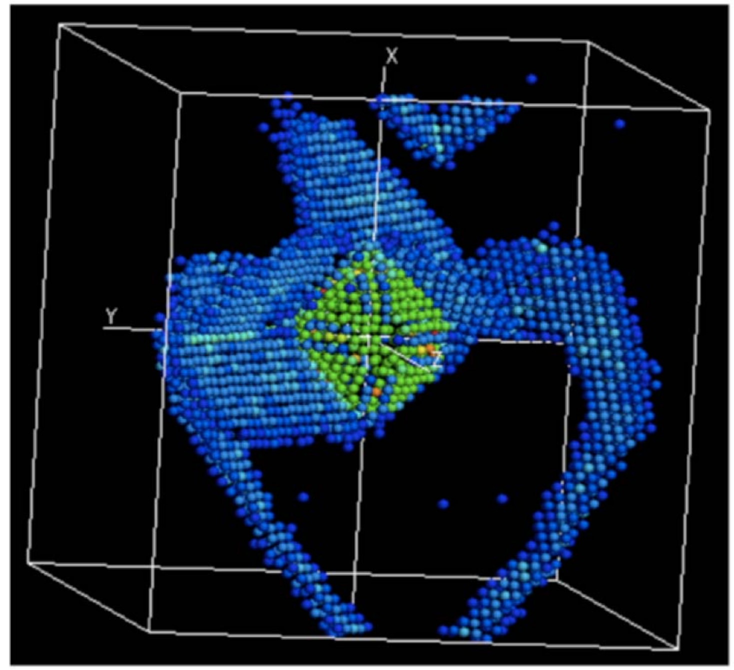
A three-pronged experimental, analytical, and modeling approach is bringing together laser and gas-gun compression experiments, constitutive modeling and molecular dynamics where model FCC and BCC metals are being investigated all the way from the mono-crystalline to the nano-crystalline regime.

This work is carried out in collaboration with Lawrance Livermore National Laboratory Scientists B.A. Remington, D.H. Kalantar, and B. Maddox.

B. Dynamic void growth in Single-crystal Copper

Studies of void growth have shown that dislocations are means to describe local stress relief, material transportation and shape change under deformation. This study concentrates on the roles and behaviors of dislocations. We aim to study all aspects of dislocation, such as plane, direction, velocity, length, concentration, energy, interaction, multiplication and annihilation, as far as Molecular Dynamics allow. As the study progresses, we have learned that some constitutive models being used in Continuum codes do not take length-scale into consideration. As we can gather so much information from Molecular Dynamics, we hope to contribute to the improvement if those constitutive models

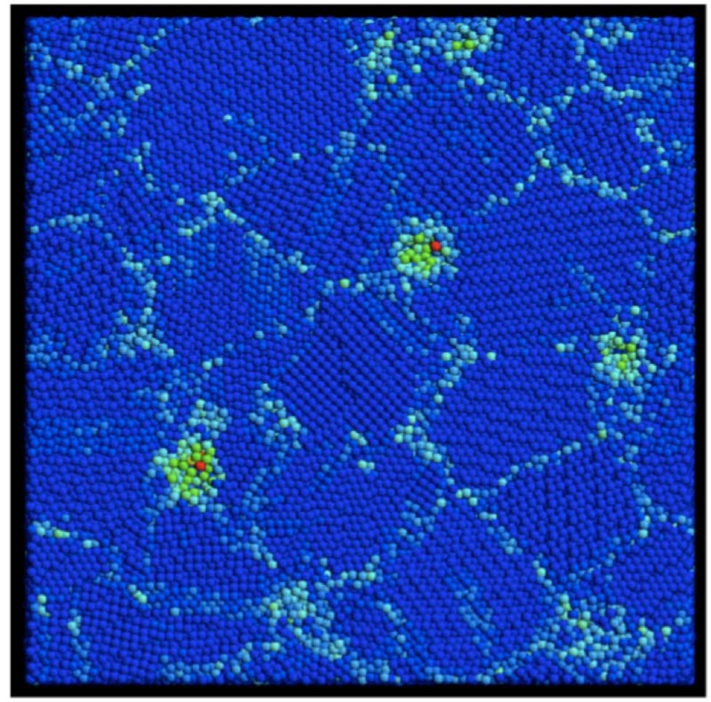
A new type of dislocation mechanism, shear loop emission, was discovered.



Meyers 250; Meyers 301; Meyers 306.

C. Plastic Deformation of Nano-crystal Nickel

Shock compression experiments have been performed on Nano-crystal Nickel samples and it has been found, by mean of Positron Annihilation method, that the measured porosity of the shocked samples remain unchanged compare to the original ones. This inspired this Molecular Dynamics experiment. Various comparable shock pressures are simulated in MD with changes in strain rates. Surprising results emerged that voids/porosity in Nano-crystal Nickel remain close to the same after the shock compression has been release, especially to zero strain. Multiple releasing methods are performed, the simulation results are compared with no voids Nano-crystal samples. We have also found the case where voids collapsed.

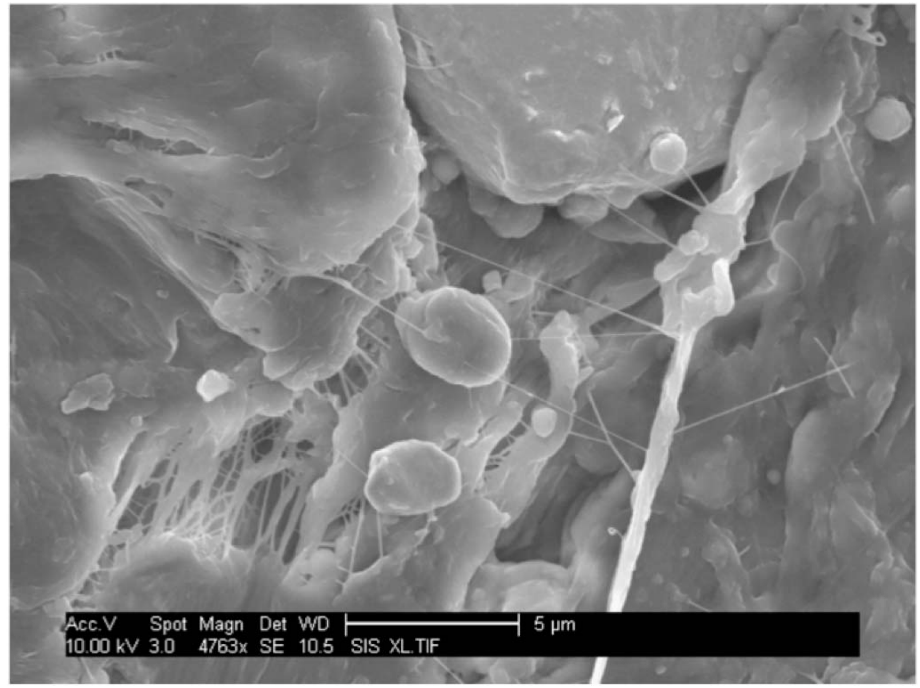


Meyers 279; Meyers 300

I. REACTIVE MATERIALS/ Shock and Shear Effects

Dynamic reactive materials have been intensively studied over a wide range of strain rates, temperatures and stress conditions. Recently, many studies on non-detonating reactive materials have focused on projectile applications in military operations in urban terrain (MOUT). The requirements are a high density and exothermic reaction initiation upon impact. The various mixtures of different metals, polymers, and non-conductive substances are proposed and investigated.

Mechanical response, including fracture pattern and mechanism, and microstructural characteristics of composite mixtures under high-strain and high-strain-rate deformation are one of major focuses in this field. Reaction of composites is examined with the help of Raman Spectroscopy and Differential Thermal Analysis (DTA). The influence of additive components in composites is also analyzed.



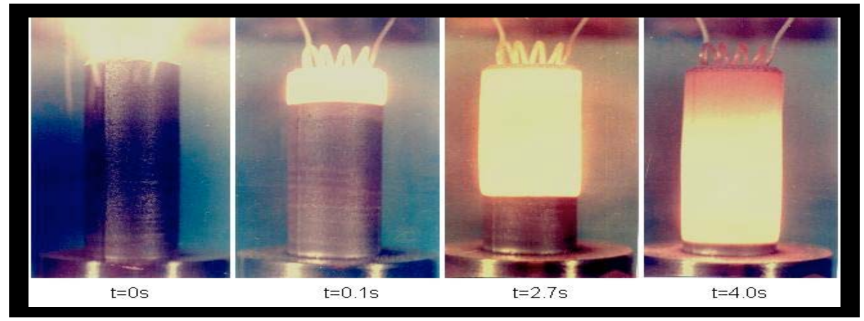
Laser shock experiments are carried out to establish the mechanisms of initiation in laminate reactive materials (Ni-Al) produced by Tim Weihs' Group at Johns Hopkins University.

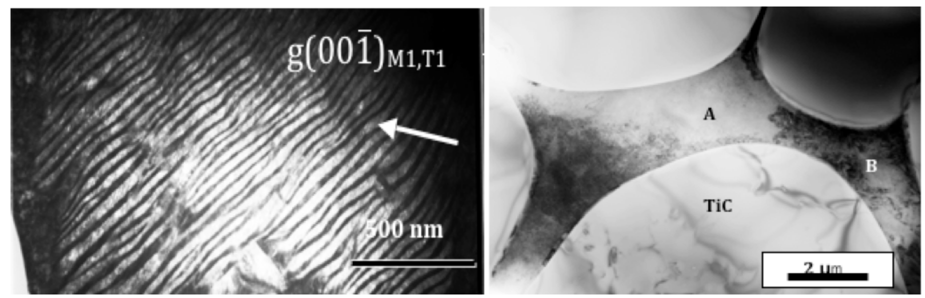
Meyers 194; Meyers 286; Meyers 294; Meyers 307

J. COMBUSTION SYTHESIS/DENSIFICATION OF CERAMICS AND COMPOSITES

The goal of this research is to synthesize, densify ceramics and composites materials. This research program has been initiated in 1988 under DARPA funding and the initial objective was to manufacture ceramic plates for armor. A great deal of fundamental research has been carried out in twenty years and This process is based on chemical exothermic reactions. Due to the evolution of the high reaction heat, the specimens' temperature is increased very fast.

The synthesis and densification of ceramics and composites can be achieved simultaneously, with applied pressure. The whole process occurs in several tens of seconds, in an economic way.
TiC, TiB3, SiC, B4C-Al2O3 , TiC-NiTi ceramics and composites have been synthesized, densified and tested and characterized. The results have been published in a series of approximately twenty papers.



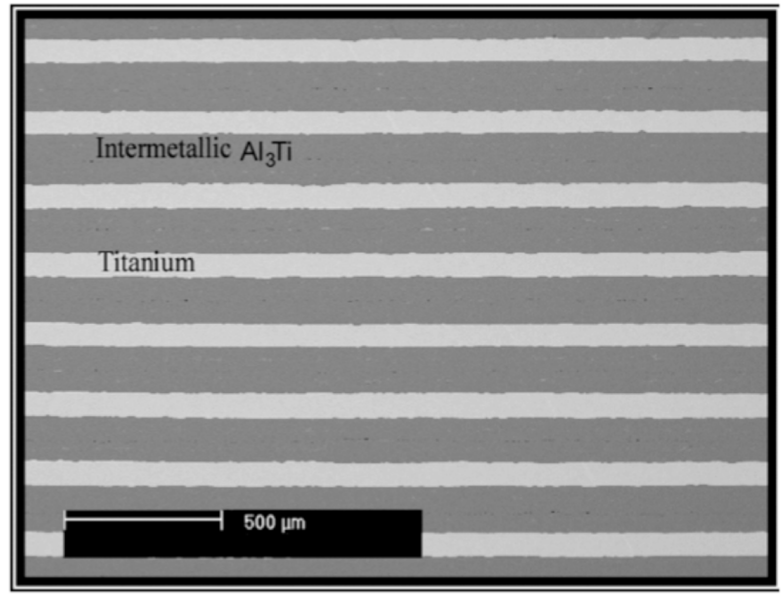


We used a large dynamic pressing machine, DYNAPAK, which was activated at a prescribed time (~10s) after the reaction was complete.
We used developed a quasi iso-static compression system using a granular pressure transmitting medium.

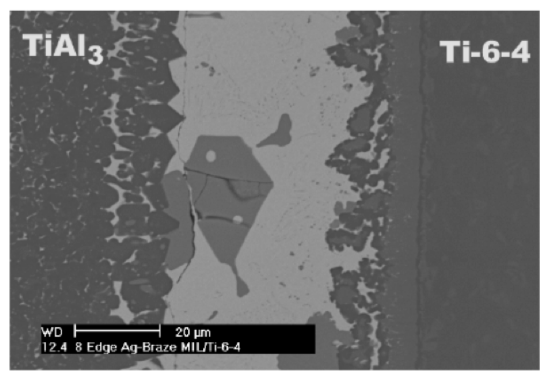
This research has been carried out in collaboration with Dr. L. W. Meyer (Germany) and Prof. E. Olevsky (San Diego State U.).
Meyers 97; 129; 131; 137; 149; 150; 151; 156; 161; 190; 203; 207; 208; 218; 217; 285

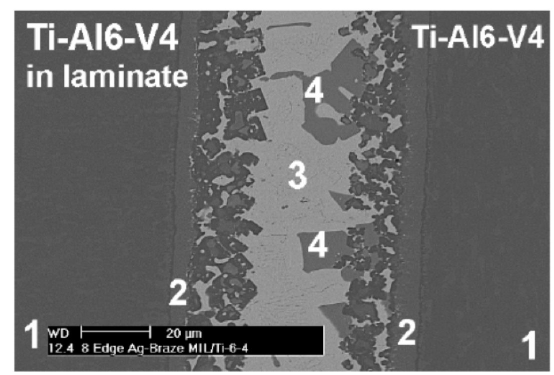
K. METAL-INTERMETALLIC LAMINATES

We investigated the mechanical properties of AlTi-Ti metal-intermetallic laminates produced by the Vecchio group using a reactive technique. The crack density was measured and the residual stresses in the structure were estimated. The anisotropy of mechanical properties was calculated and compared to experimentally observed values. We have also investigated experimentally and computationally the evolution of damage in these laminates during cooling and during mechanical testing.



This program was funded by DARPA with K. Vecchio as PI and was carried out in collaboration with Profs. E. Olevsky and Lutz Kruger.

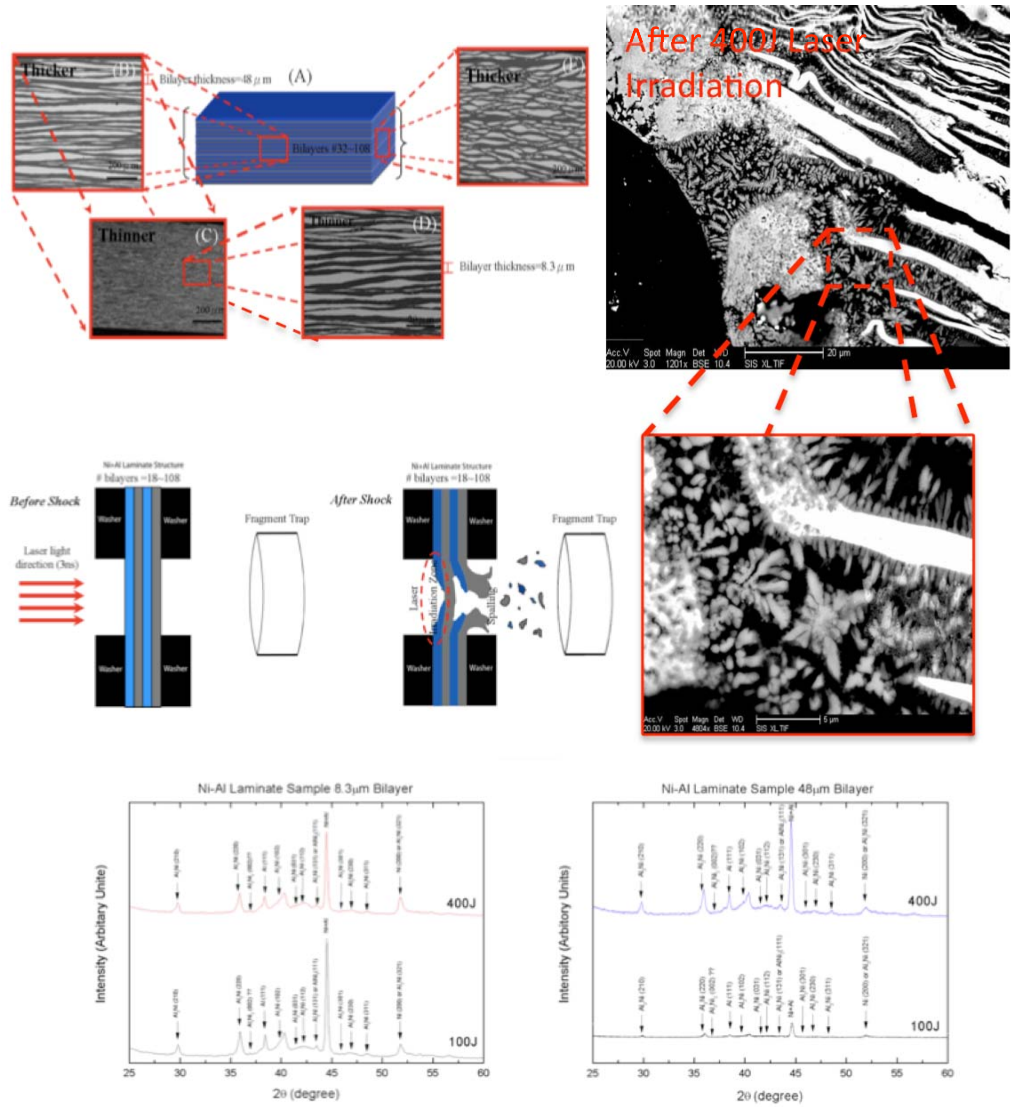




Meyers 249; Meyers 275; Meyers 246

L. Reactive Materials (Laminate Structures)

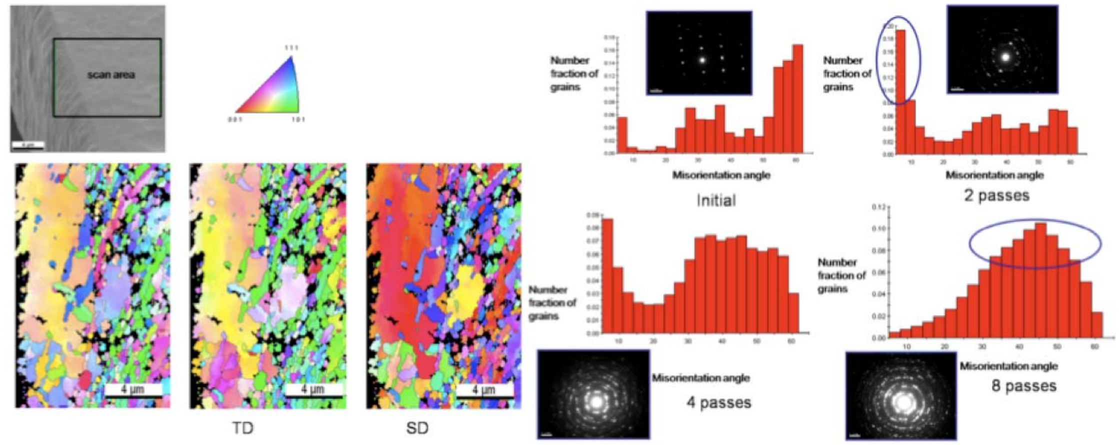
A reactive laminate structure was conducted . The reactive laminate structure was formed by cold-rolling from laminate sheets. After the high deformation rolling process, the materials may have potential of chemical reaction. We use different energies of laser to irradiate the sample. After the laser exposure, the qualitative examination, such us SEM, X-ray, EDX, was conducted to investigate the reaction of the interface of laminate structure. The research was funded by ONR MURI N00014-07-1-0740. It cooperates with V. Nesterenko (UCSD), T. P. Weihs (Johns Hopkins).



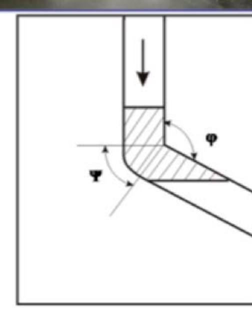
M. Ultrafine Grained Metals

•Equal-Channel Angular Processing (ECAP)

ECAP was used to produce copper with a grain size in the 200-500 nm range. This required several passes, each one providing a shear strain of approximately 1. Different pass sequences were compared, with sequence B_c providing the most effective grain reduction. A model for the reduction in grain size was developed and the quasistatic and dynamic properties of this material determined.



We have explained how the ultrafine grained structure is formed by means of a rotational recrystallization mechanism akin to the one producing the nanocrystalline structure in adiabatic shear bands.

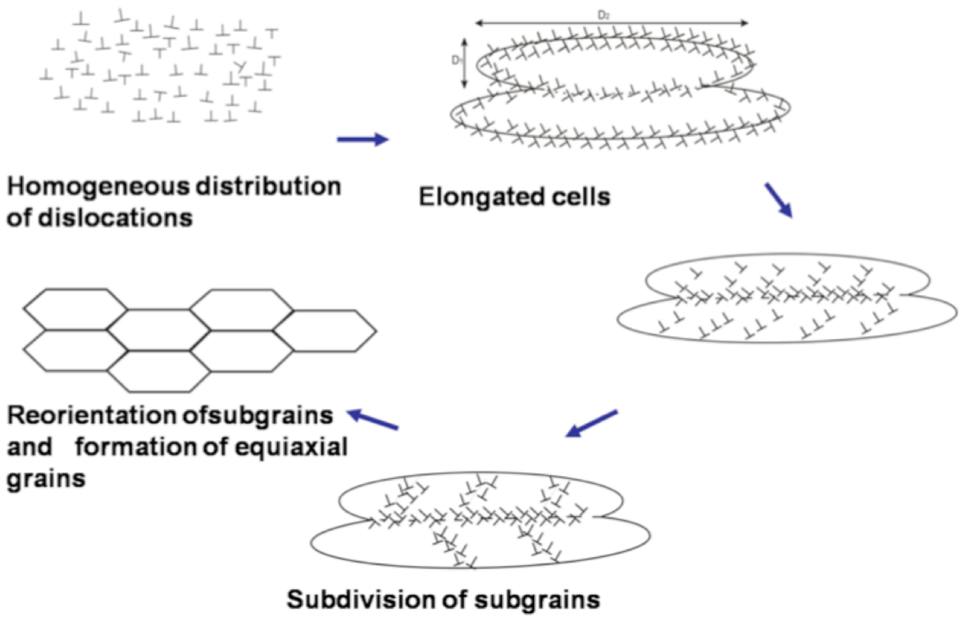


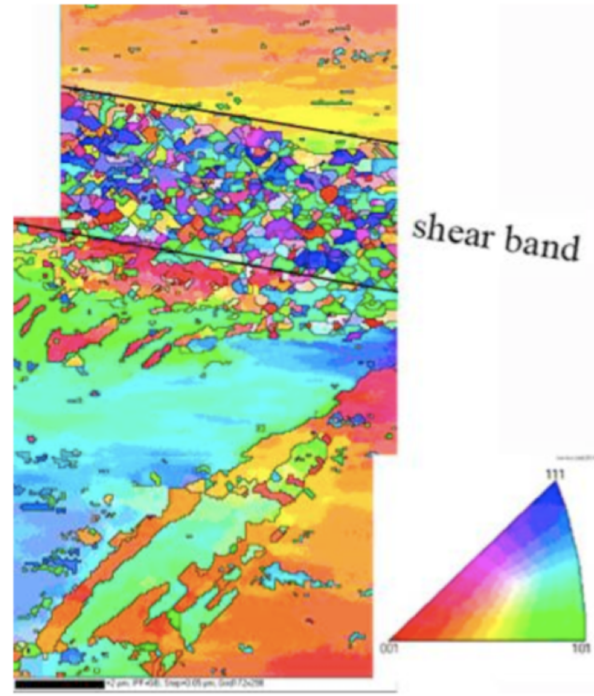
Die specification -
H-13 tool steel: 6'× 4'× 2'
Outer arc: smooth 20º
Inner angle: 102º and 90º
Channel diameter: 3/8"

This research was funded by the National Science Foundation NIRT program (PI: R.J. Asaro)

Meyers 278; Meyers 287; Meyers 297

N. SHEAR LOCALIZATION





Adiabatic shear bands are a prominent feature in the high-strain rate deformation. Our research into the topic has been quite extensive, with papers published. The research has yielded two important conclusions:

•We have demonstrated incontrovertibly that a rotational dynamic recrystallization mechanism is responsible for the formation of the ultra-fine grain structure observed in shear bands.

•We have demonstrated that the adiabatic shear bands organize themselves with a characteristic spacing, that is material dependent. This self organization is the result of an evolving characteristic spacing between bands, that has been successfully compared with theories developed by Ockendon and Wright, Grady, and Molinari.
Meyers 220; 235; 236; 251; 252; 296; 302

PAST RESEARCH

1. Dynamic Properties of Ductile Metals

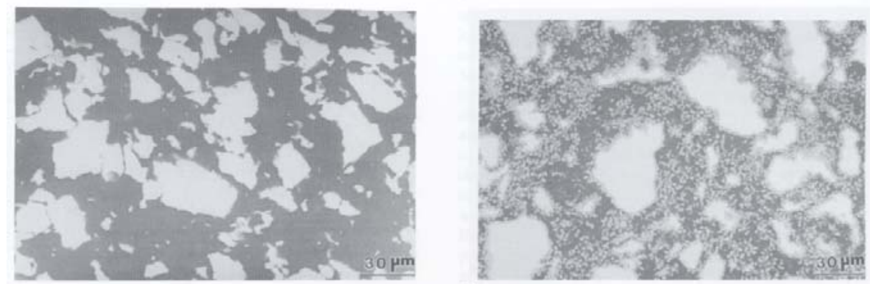
Since 1972, we have investigated the high-strain-rate response of the following metals:

1. Tantalum, a model BCC metal and an important component of explosively forged projectiles. This work included implementation of constitutive equations, shock-wave effects, and microstructural evolution.
2. Copper, a metal used in shaped charges. We have studied copper with different grain sizes and its shock-wave response, and discovered that the hardening is much more pronounced for large grain sizes. This has implications for shaped charges, and we proposed that high-strain-deformation can lead to an ultrafine grained structure leading to super-plasticity. We have also investigated monocrystalline copper by shocking it from an initial temperature of 88 K to minimize post shock recovery effects.
3. Nickel. We discovered the phenomenon of work softening in shocked nickel, which we later confirmed in copper.
4. Fe-Ni-Cr alloys, including stainless steel.
5. Inconel 718, a nickel-base superalloy.
6. This research, which was initiated with my doctoral studies, was continued in Brazil, at the Military Institute of Engineering, where we set up an explosives laboratory and developed the explosives required for the flyer plate experiments.
7. I collaborated extensively with Prof. H. -J. Kestenbach, Prof. L. E. Murr and Dr. D. Lassila on these projects.

2. Shock and Shear Induced Chemistry

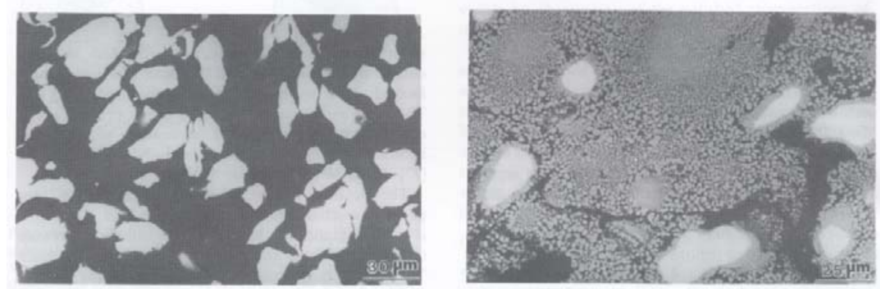
We carried out extensive investigations into shock-induced reactions by subjecting systems to explosive consolidation and collapse in a cylindrical geometry. We demonstrated that shear localization increased the susceptibility to chemical reactions. Professor Batsanov (Mendeleev Institute, Moscow) and Prof. Nesterenko (formerly of the Institute of Hydrodynamics, Novosibirsk) , and Dr. R. Graham, and Dr. W. Nellis were my principal collaborators in this area.

Meyers 100; 152; 167; 173, 201



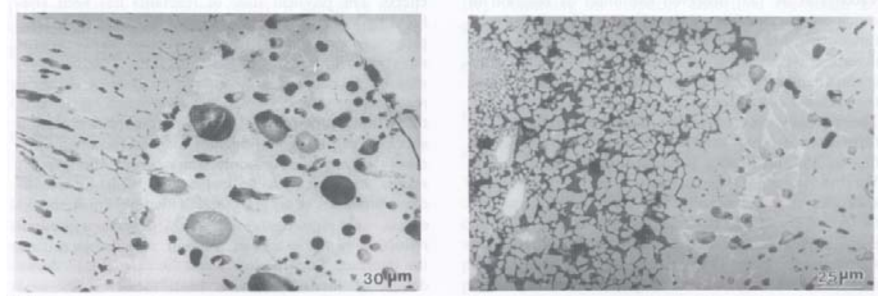
(a) (b)

Fig. 3. (a) Unreacted and (b) partially reacted regions for Nb + 2Si system (symmetric shock compression).



(a) (b)

Fig. 4. (a) Unreacted and (b) partially reacted regions for Mo + 2Si system (symmetric shock compression).

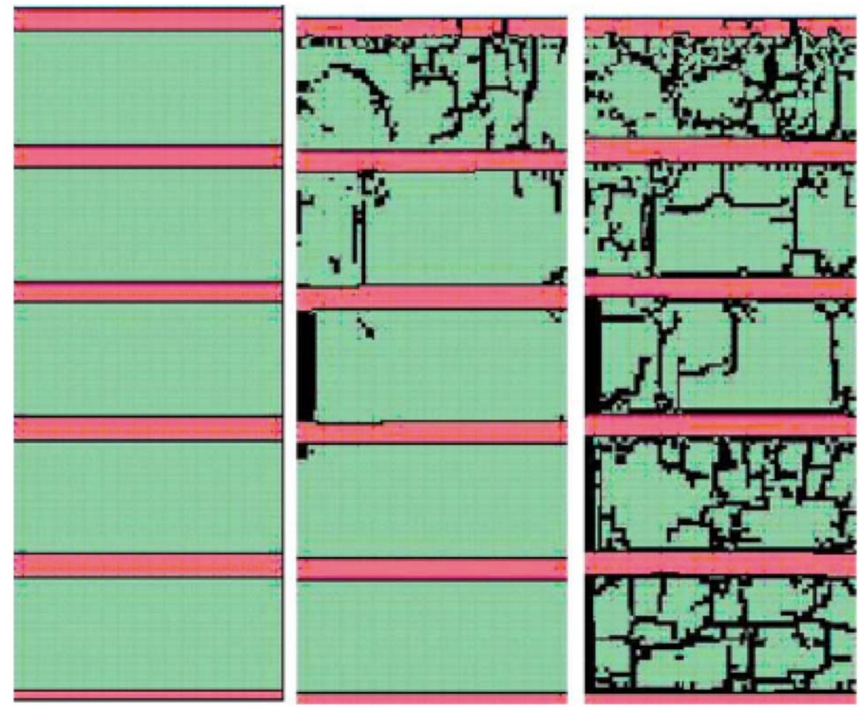


(a) (b)

Fig. 5. Fully reacted regions from Mach stem from (a) Nb + 2Si system; (b) Mo + 2Si (symmetric shock compression).

3. Dynamic properties of Steel Welds

We studied HSLA, a Navy ship steel. We tested the material away from the weld and in the weld region and established the quasistatic and dynamic response, which were used for implementation into constitutive equations used Prof. Benson in simulations.
Meyers 212
Meyers 249



Evolution of the internal fractures of 20% Ti-6-4 composite at ε=1000/s

4. Shock Consolidation of Powders

We carried out extensive explosive compaction experiments for a period of ten years (1980-1990). During the 80s, the production of rapidly-solidified metallic powders with refined microstructures required new means of consolidation other than hot pressing and HIPing. These latter processes created temperature excursions that destroyed the fine scale introduced by rapid solidification. Thus, intense efforts at producing bulk parts from the fine powders were carried out worldwide. One of the first explosive compaction experiments on rapidly-solidified powders was carried out by Meyers, Murr, and Gupta on a MarM 2000 superalloy produced by pratt7Whitney (RSR process)...

They demonstrated the proof-of-principle ; the fine structure of the powder was retained . A fine layer of molten and rapidly resolidified layer formed the interface between the particles. This fine layer was either nanocrystalline or glassy. Thus, the intrinsic high strength of powder was retained.

There was considerable industrial interest, and we were funded (at the Center for Explosives Technology Research, in Socorro) by Prat&Whitney, GE, McDonnell Douglas. Later, materials such as diamond, boron nitride, and boron carbide. Prof. A. Sawaoka, Tokyo Institute of technology, and his former student, Dr. T. Akashi (Sumitomo) spent two years at CETR carrying out intensive research on the shock consolidation of powders and synthesis of new compounds. We also had extensive support from Sandia National Laboratories, through collaborations with Dr. Robert Graham. Dr. Naresh Thadhani was funded by DARPA to make large scale diamond compacts. A variety of different experimental configurations were used and/or developed: Sawaoka setup, in which we adapted the gas gun capsules used in the Sawaoka lab to explosives.

Sandia Bear capsules. These capsules are the Baby Bear and Mamma Bear series developed by R. Graham. They were coupled with computer simulations that enabled the prediction of the pressure and temperature history at all points inside capsule. Thus, we had a quantitative control of the conditions and were able to match our predictions of ideal compaction (a specified fraction of molten material) with the prediction from the simulation. Double tube geometry developed by Meyers and Alex?? This modification of the cylindrical geometry produced a higher pressure, at a specified explosive detonation velocity. It produced much improved compacts without Mach stem in the center.

We successfully scaled up the process producing cylinders with ~20 kg. Further scale up was demonstrated. We developed a technique of high-temperature consolidation and produced high quality compacts of ceramics and intermetallics by this method.

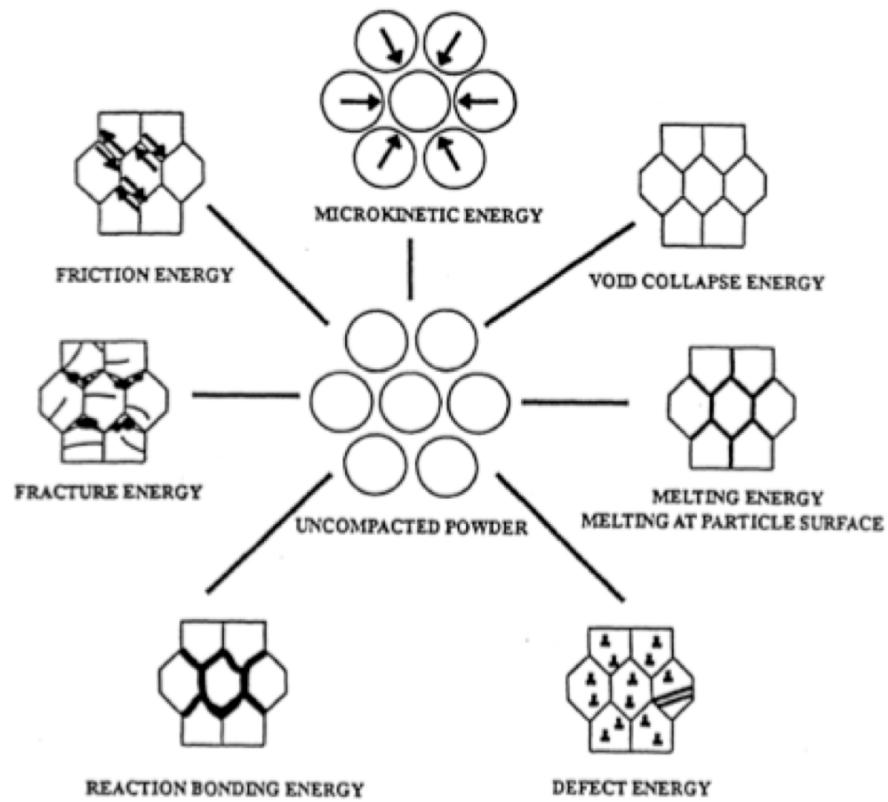
We shock consolidated metals, nickel-base superalloys, intermetallics (TiAl and Ti_3Al), aluminum alloys, and ceramics (diamond, SiC,BN, B_4C, and others).

We gradually realized that we had a conundum in our hands: ‘softer’ metals required lower energy for consolidation and were amenable to this process. The lower pressures produced, invariably, reflected tensile pulses that were not damaging to the structure. However, ‘harder’ materials (ceramics, intermetallics, metallic glasses, etc), which were of great interest, These materials required high pressures, which produced higher amplitude reflected tensile pulses. These materials also had lower toughness, and would invariably exhibit cracks on recovery. This severely limited their tensile ductility. We wrote a paper pointing out these inherent limitations of shock compaction.

The verdict on explosive consolidation seems to be, after a global effort of over twenty years: it is not feasible, by itself.
One possible route that seems possible is to use explosives to densify hard powders. This is then followed y machining of the green parts and final sintering/HIP. Densification can be accomplished at lower pressures than compaction. Additionally, any eventual flaw can be healed by post densification thermal means.

The following are the most significant results:

•In order to increasing pressure while minimizing the formation of a central mach stem, a double tube system was developed and successfully tested.
•The use of chemical reactions to increase the local temperature during consolidation was applied successfully.
•A detailed analysis showed that cracking, an elusive problem in shock- wave consolidation, is unavoidable. This is a great limitation and will most probably restrict the technical goal implementation of this technique.

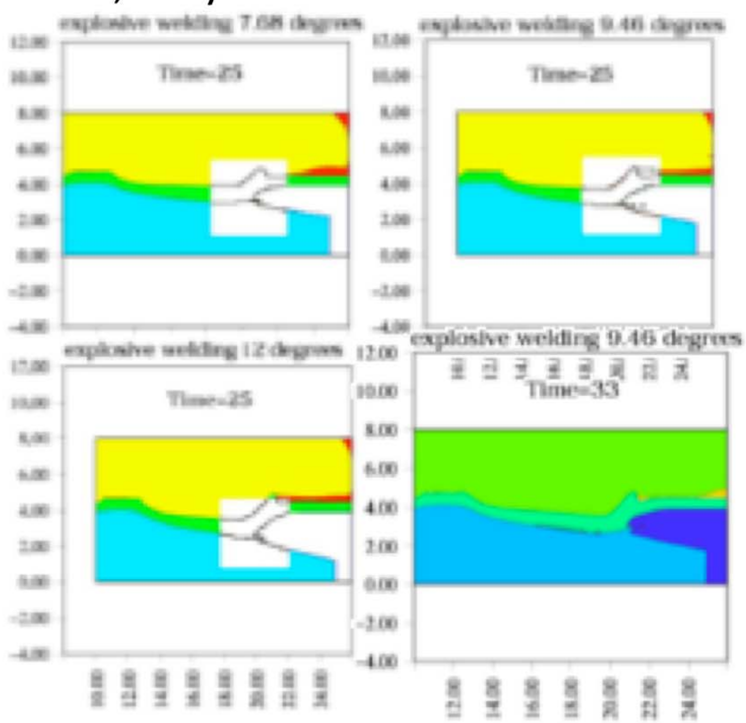


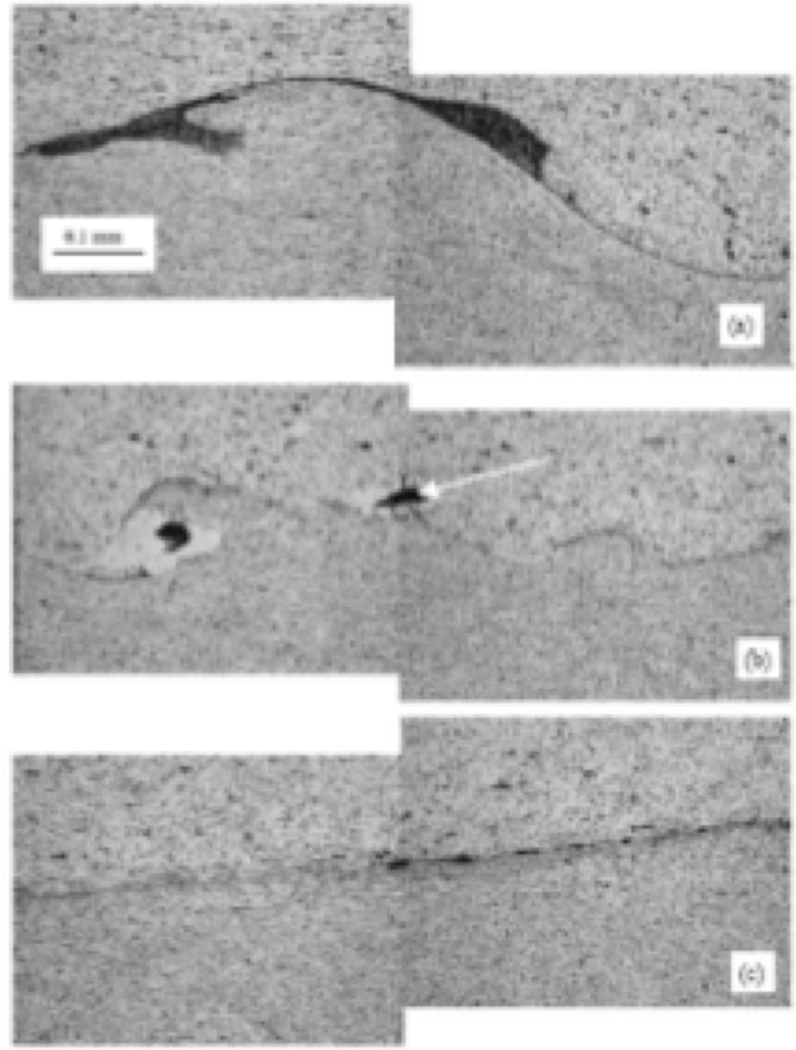
Meyers 45; 82; 86; 88; 90; 94; 100; 113; 114; 115; 148; 120; 150; 158; 193 202;

5. Explosive welding for Space Applications

We investigated an explosively formed capsule that was considered by NASA for use in the Mars Lander mission and demonstrated, through experiments, modeling, and analysis, that the process carried the potential of trapping Mars bugs and bringing back to earth. This work and the general UCSD environment were the inspiration for the novel "Mayan Mars."

Meyers 248; Meyers 256

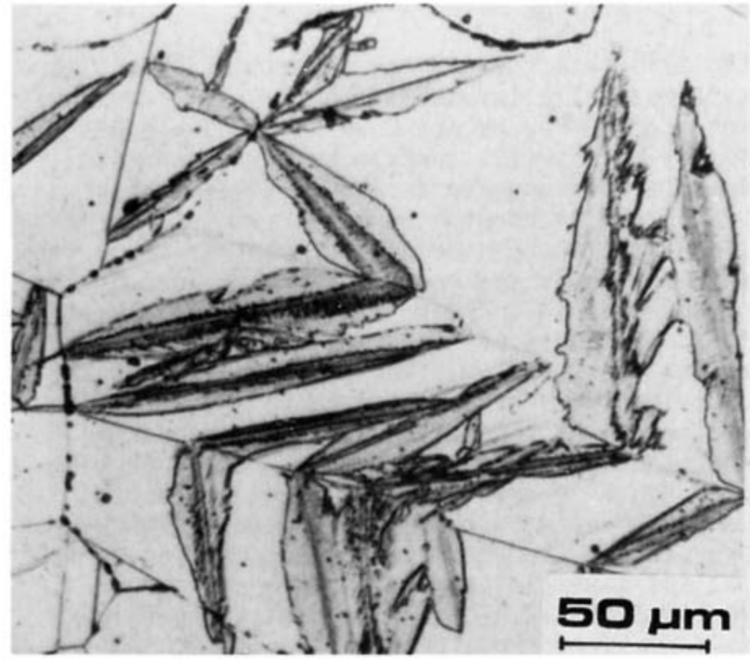


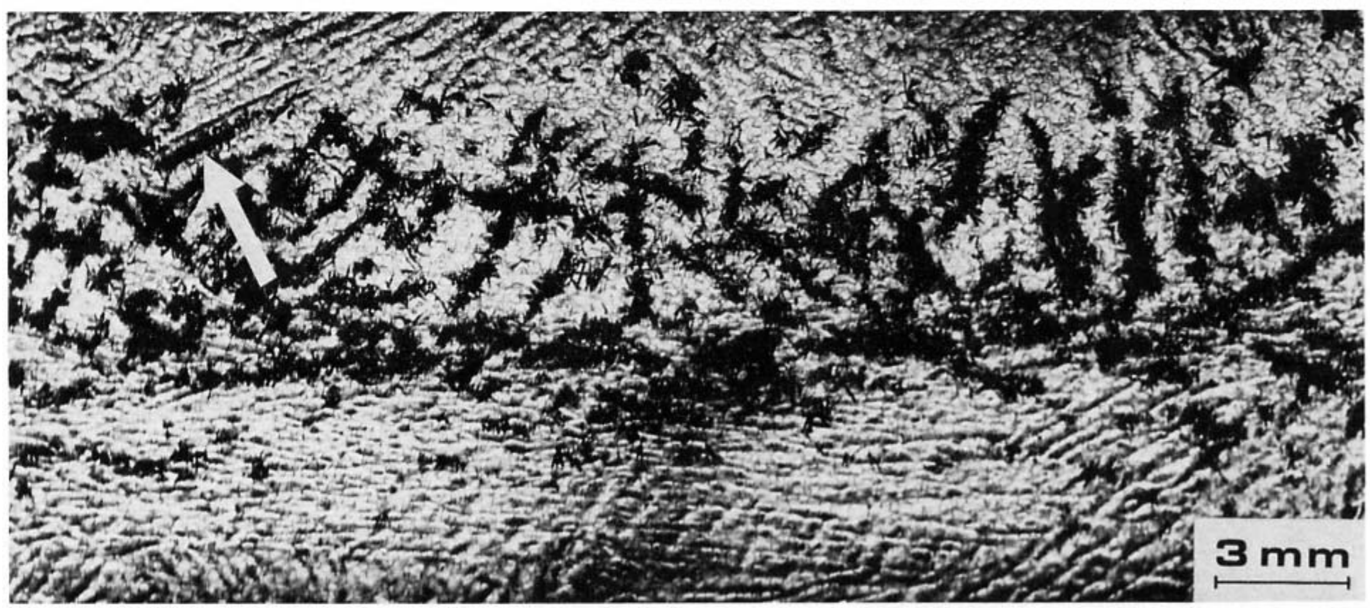


6. Martensitic Transformations

We discovered that the martensitic transformation is a prominent feature in shock-compressed Fe-Ni alloys and applied this technique to determine the transformation kinetics on the microsecond regime. This enabled us to show, for the first time that athermal martensite is an ultrarapid isothermal martensite.

By reducing the pulse duration even further, we were able to determine the nucleation time for martensite which is in the 20-50 ns range.



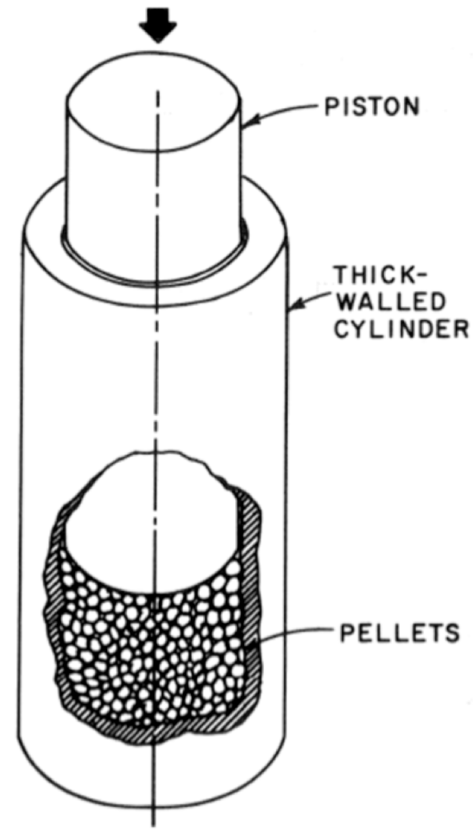


Meyers 57; Meyers 79
Meyers 80; Meyers 81
Meyers 84; Meyers 87

7. Iron Ore Agglomerates: Mechanical Properties and Reduction

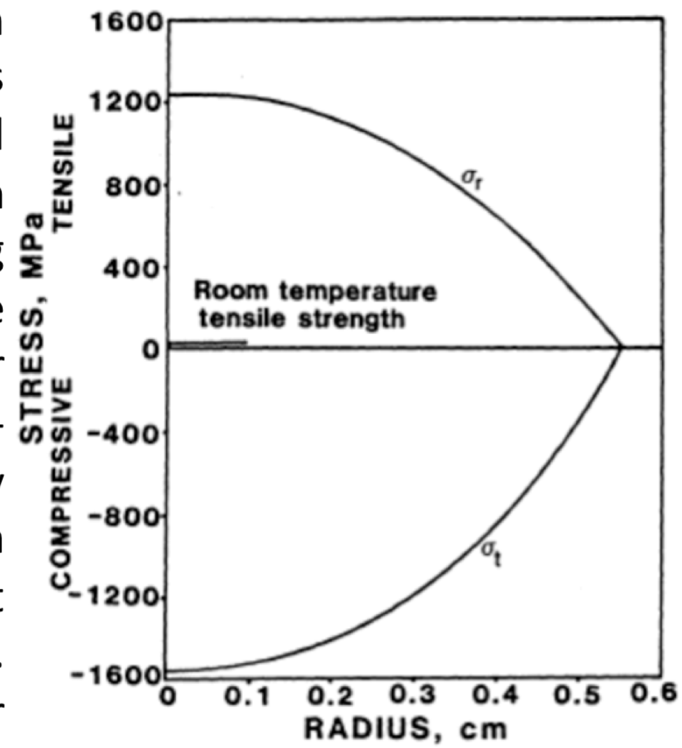
The analysis of the phenomena involved in determining the compressive strength of iron-ore agglomerates leads to the identification of important parameters. It is shown mathematically that the pellet rupture strength is proportional to the cross –sectional area. The variation in strength between individual pellets of identical composition and subjected to identical treatments is due to internal voids of varying sizes that act as stress-concentration sites.

Two novel testing procedures are proposed. The first consists of testing the pellets between two plates having three steel spheres each. This configuration simulates much better the environment actually encountered by the pellets. The second procedure consists of a thick-wall cylinder in which a piston penetrates; a large group of pellets is rested. This latter test presents significant advantages over the conventional testing procedure; the main one is that one single test is sufficient to characterize the mechanical response of the pellets.



The objectives of this investigation were (a) to determine the effect of reduction temperature on the strength of iron ore agglomerates and (b) to develop enhanced understanding for the cracking associated with reduction. Iron-ore agglomerates from two sources (Samarco Mineracao and Bethlchem Steel) were reduced in a hydrogen atmosphere at temperatures varying from 873 K to 1373 K at intervals of 100 K and times varying from 30 to 300 minutes. The compressive strength at the ambient temperature of the pellets was determined after the various reduction treatments by using a piston-and-cylinder testing technique and computing the energy required in crushing them. The highest strength, at a specific level of reduction, was found after reduction at 1073 K, for both the Samarco and Bethlehem pellets. Profuse cracking of the pellets was observed after reduction. These cracks led to a weakening of the pellets. A mechanism for reduction-induced cracking, based on internal stresses due to volume changes produced by the chemical reactions, is presented.

Meyers 43; 56; 64;

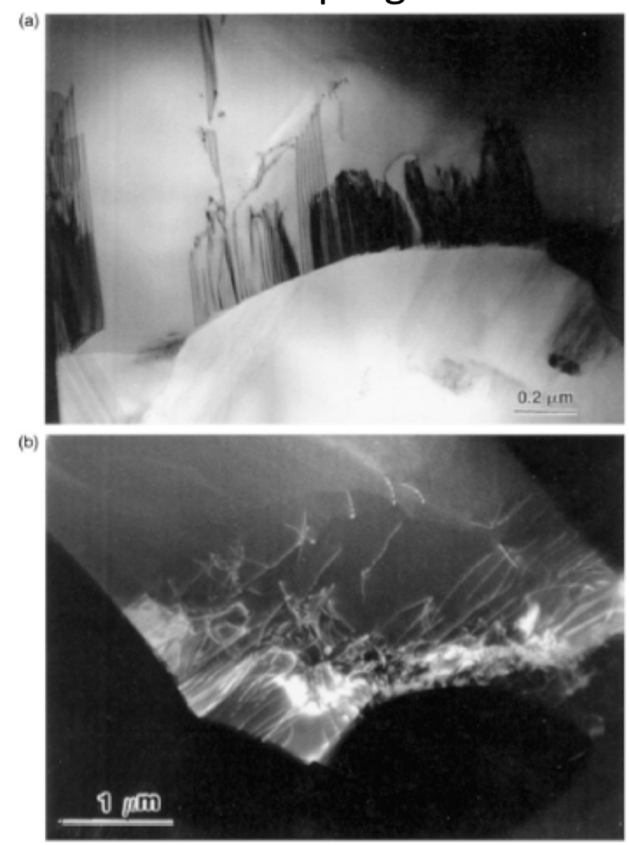


(a)

8. Dynamic Properties of Ceramics for Armor Applications

During the 80s we carried out one of the first studies on the dynamic response of alumina. We used impact in a gas gun to generate compressive and tensile pulses and found out that a precompression creates a network of cracks which reduce the subsequent tensile strength of the ceramic. This study was inspired by an earlier investigation which focused on minerals (quartz monzonite) . We subjected quartz monzonite to plane wave compression in a flyer plate impact geometry and in a gas gun geometry and subsequently determined the level of damage in the structure. We did this e measuring the fragment size and by doing

During the 1990s we focused, under ARO MURI funding, on a fundamental program directed at elucidating the damage mechanisms in ceramics.



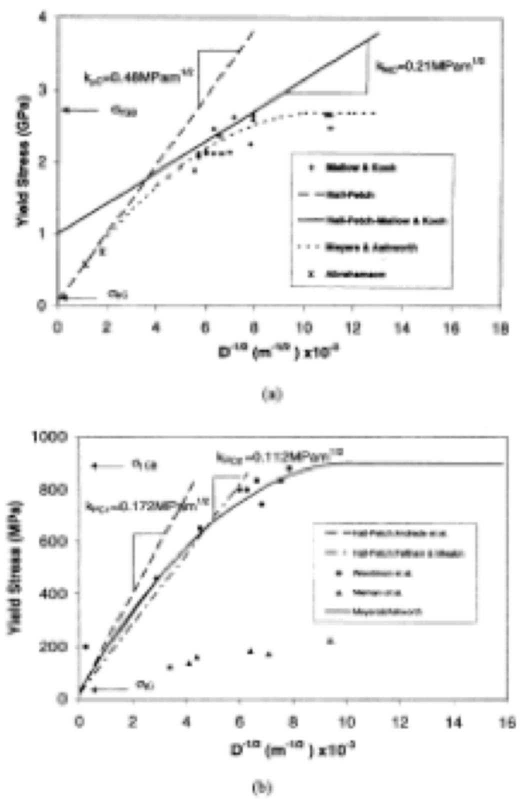
We showed that silicon carbide impacted at high velocities exhibits profuse dislocations. These dislocations were proposed to generate cracks. Thus, it was shown that microplasticity is important at high compressive stresses. We also looked at shear localization in SiC and $Al_2 O_3$ and showed that it plays an essential role in post fracture process. A specific mechanism for localization was proposed based on observations of solid and granular ceramics subjected to the thick-walled cylinder collapse process.

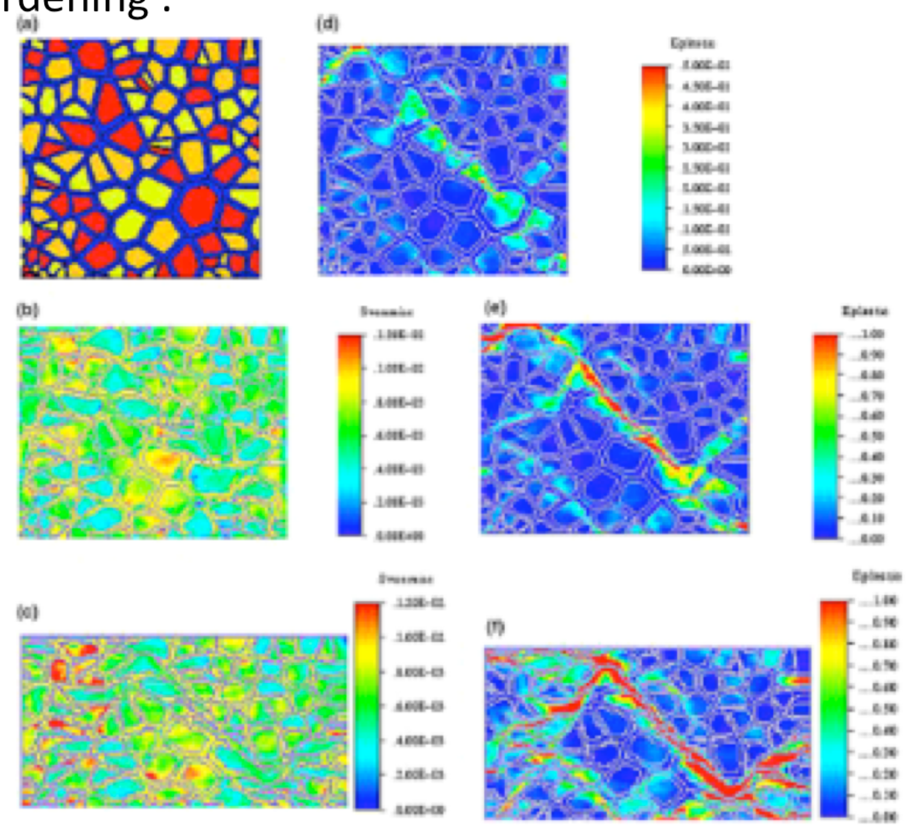
Meyers 102; 164; 171; 172; 183; 184; 192; 200

9. Grain Size Effects on Strength

In 1980, we proposed a mechanism for the influence of the grain size on the yield strength of metals based on elastic incompatibilities between adjacent grains. This model, proposed with A. Ashworth, has been further developed using finite element formulation with D. Benson. It has been extended to the nanocrystalline regime and has been shown to predict a deviation from the classical Hall-Petch equation for small grain sizes. The basic idea is that geometrically necessary dislocations are generated in regions adjacent to the grain boundaries. These dislocations have slip planes that interact or cross slip. Thus, a highly work hardened layer forms close to the grain boundary (the mantle region) whereas the insides of the grains have a less pronounced hardening .

Meyers144
Meyers146
Meyers230
Meyers227
Meyers258





10. Annealing Twin Formation

We proposed a model for annealing twin formation by which they ‘pop out’ of the grain boundaries and grow , by glissile motion of the non-coherent twin boundary, into the grains, leaving behind parallel coherent twin boundaries. This ‘pop out’ mechanism has since been widely discussed in the literature.

Picture from Meyers & Murr

We also modified the Gleiter mechanism for annealing twin formation by combining it with a migrating grain boundary. This modified mechanism explains how incomplete double-sided twins are formed .

Meyers 27

Meyers 77

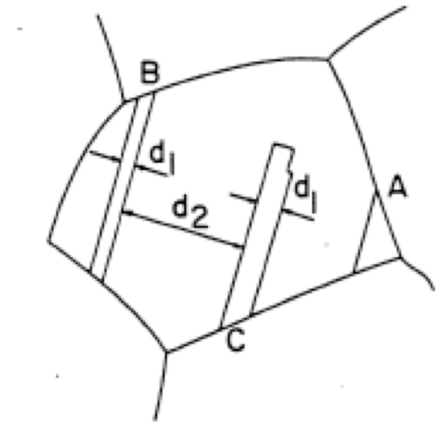


Fig. 9. Three types of annealing twin morphologies observed in f.c.c. metals and alloys. *A* is a grain corner twin; *B* is a complete parallel-sided twin; *C* is an incomplete parallel-sided twin.

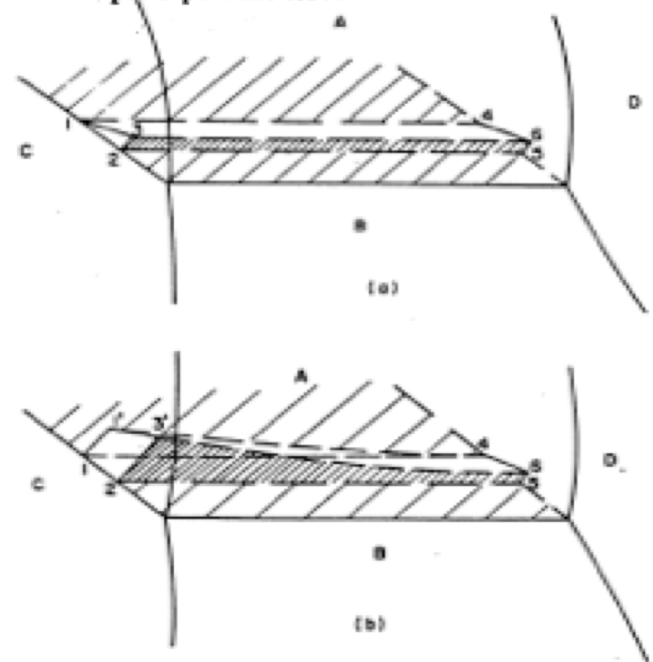


Fig. 3. Three-dimensional representation of twin nucleus and incipient twin formation which appears as a ledge or double ledge in the grain boundary plane. (a) Small triangular nucleus as in Fig. 1(b). (b) Popping out of incipient twin along one portion of the grain boundary to form a partially grown annealing twin band.

11. Spalling/ Dynamic Fracture

The fundamental mechanical aspects of dynamic fracture in metals are presented, with emphasis on spalling produced by the interactions of shock and reflected tensile waves. The major research efforts conducted in this area are reviewed; the process has been successfully described as a sequence of nucleation-growth-coalescence of voids or cracks. Quantitative models predicting the extent of damage have been successfully compared with experimental observations, by incorporating them into computer codes.

A number of metallurgical aspects of importance are discussed: failure initiation sites, crack, propagation paths, strain-rate-dependent ductile to brittle transition, grain size effect, interchange in spall morphology when the 13 GPa stress is exceeded. This change is documented and interpreted in terms of the α(BCC)➔ε(HCP) phase transformation undergone at that pressure. Micromechanical models describing the growth of voids in terms of dislocation motion are discussed.

Meyers 53; Meyers 60; Meyers 76

13. Fundamental studies on shock-wave compression

In 1978 we proposed a mechanism by which dislocations are generated at the shock front. Essentially, dislocation loops are homogeneously nucleated once the shear stress due to the applied pressure reaches a critical level. In contrast with the early model by C. S. Smith, the homogeneous nucleation model does not require supersonic dislocations. Experimental observations and molecular dynamics simulations have since confirmed this mechanism.

Meyers 6; Meyers 11;
Meyers 22; Meyers 28;
Meyers 30