MODELING HOLLOW SPHERE CELLULAR METALS AS A RANDOM MICROSTRUCTURE

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Steel Foam

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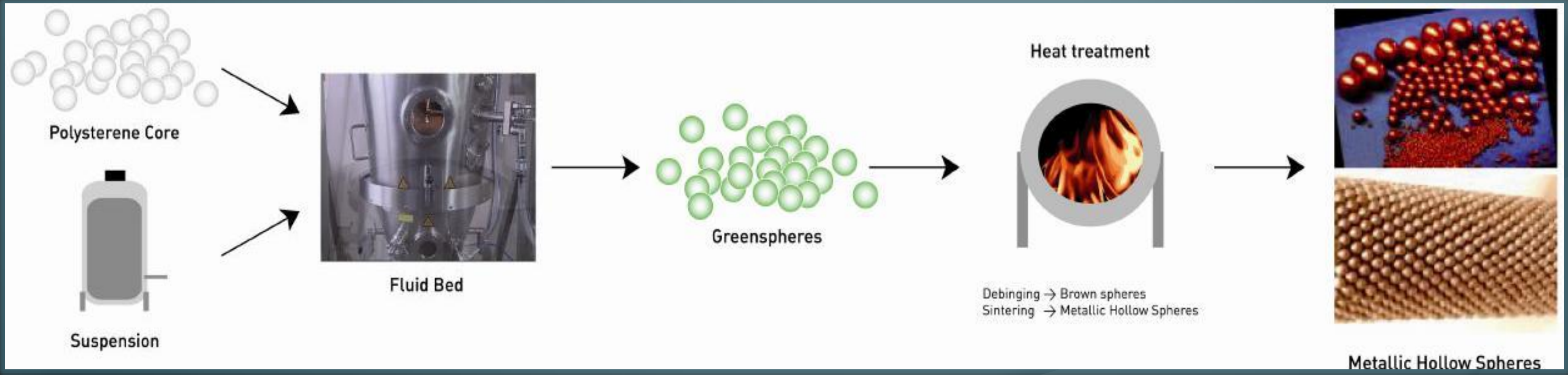
Outline

- Introduction
- Previous Modeling Research
- Random Geometry Generation
- Validation
- Simulation Matrices
- Conclusions

Gao et al 2008

Hollow Sphere Cellular Metals

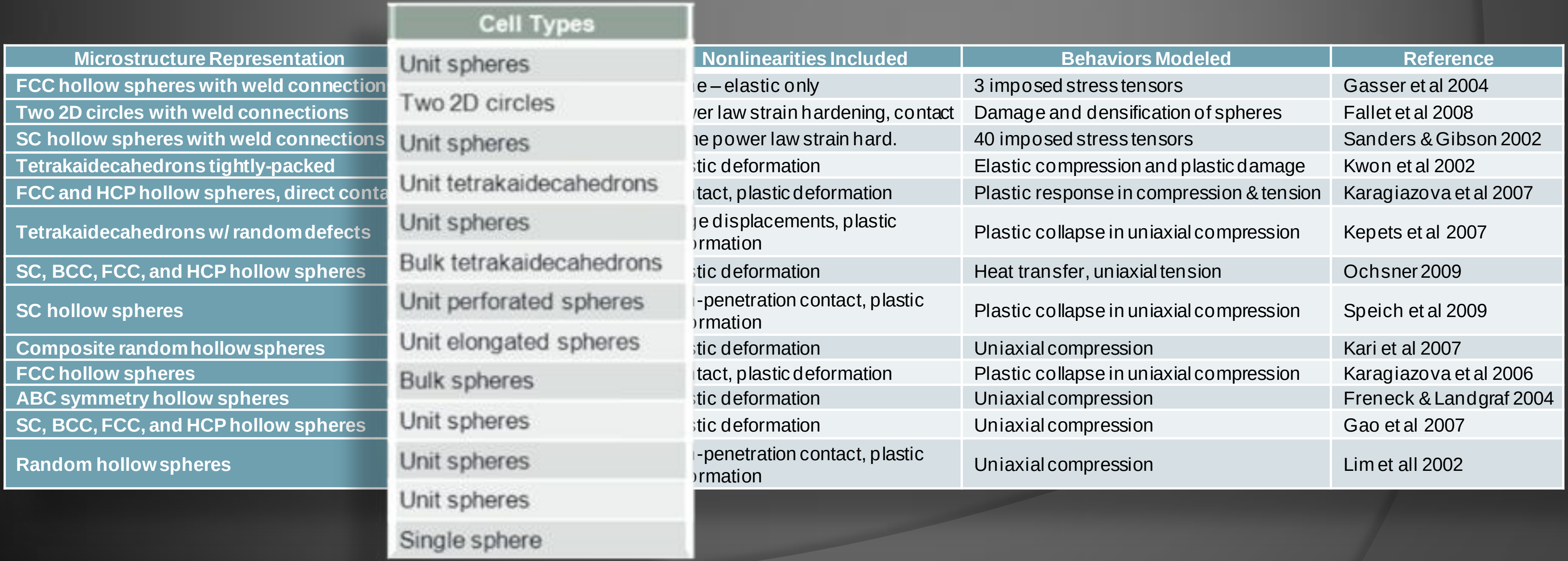
- High stiffness to weight ratio, great energy absorbers
- Cellular aluminum already used in automotive, aerospace industries
- Hollow sphere manufacturing method characterized by consistent properties, partially open-celled structure
  - Particularly useful for high melting point metals such as steel
- Structural applications being investigated
  - Experimental testing is expensive, so computational modeling is desirable



Hollow spheres manufacturing process (Oechsner 2009)

Previous Modeling Research

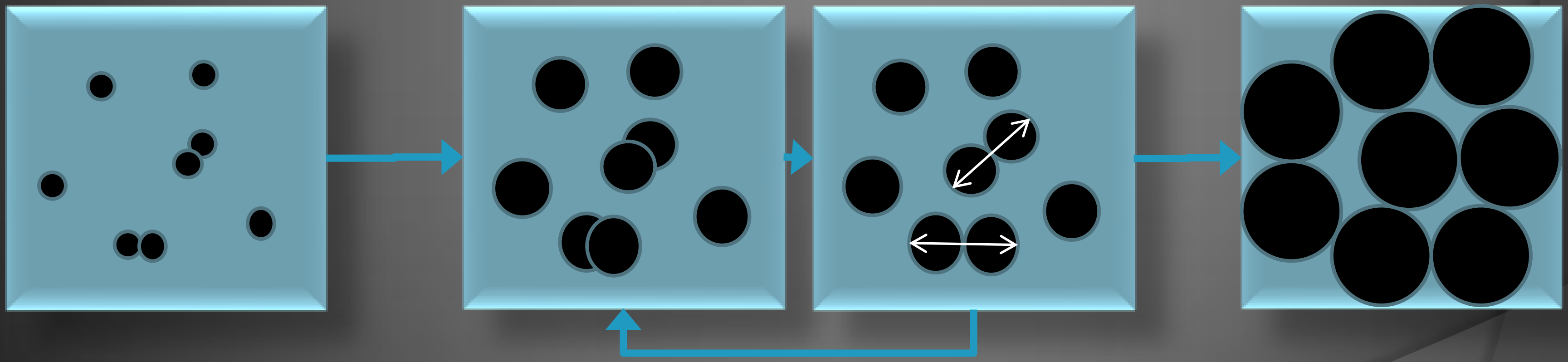
- Previous computer simulations have approximated hollow spheres foams by a regular stacking pattern
  - Usually face-centered cubic (FCC) or simple cubic (SC) structures
  - These have been calibrated experimentally, but are only accurate over a small subset of hollow spheres foams



Microstructure Representation	Cell Types	Nonlinearities Included	Behaviors Modeled	Reference
FCC hollow spheres with weld connection	Unit spheres	e – elastic only	3 imposed stress tensors	Gasser et al 2004
Two 2D circles with weld connections	Two 2D circles	ver law strain hardening, contact	Damage and densification of spheres	Fallet et al 2008
SC hollow spheres with weld connections	Unit spheres	e power law strain hard.	40 imposed stress tensors	Sanders & Gibson 2002
Tetrakaidecahedrons tightly-packed	Unit tetrakaidecahedrons	stic deformation	Elastic compression and plastic damage	Kwon et al 2002
FCC and HCP hollow spheres, direct conta	Unit spheres	tact, plastic deformation	Plastic response in compression & tension	Karagiazova et al 2007
Tetrakaidecahedrons w/ random defects	Bulk tetrakaidecahedrons	ge displacements, plastic ormation	Plastic collapse in uniaxial compression	Kepets et al 2007
SC, BCC, FCC, and HCP hollow spheres	Unit perforated spheres	stic deformation	Heat transfer, uniaxial tension	Ochsner 2009
SC hollow spheres	Unit elongated spheres	-penetration contact, plastic ormation	Plastic collapse in uniaxial compression	Speich et al 2009
Composite random hollow spheres	Bulk spheres	stic deformation	Uniaxial compression	Kari et al 2007
FCC hollow spheres	Unit spheres	tact, plastic deformation	Plastic collapse in uniaxial compression	Karagiazova et al 2006
ABC symmetry hollow spheres	Unit spheres	stic deformation	Uniaxial compression	Freneck & Landgraf 2004
SC, BCC, FCC, and HCP hollow spheres	Unit spheres	stic deformation	Uniaxial compression	Gao et al 2007
Random hollow spheres	Single sphere	-penetration contact, plastic ormation	Uniaxial compression	Lim et all 2002

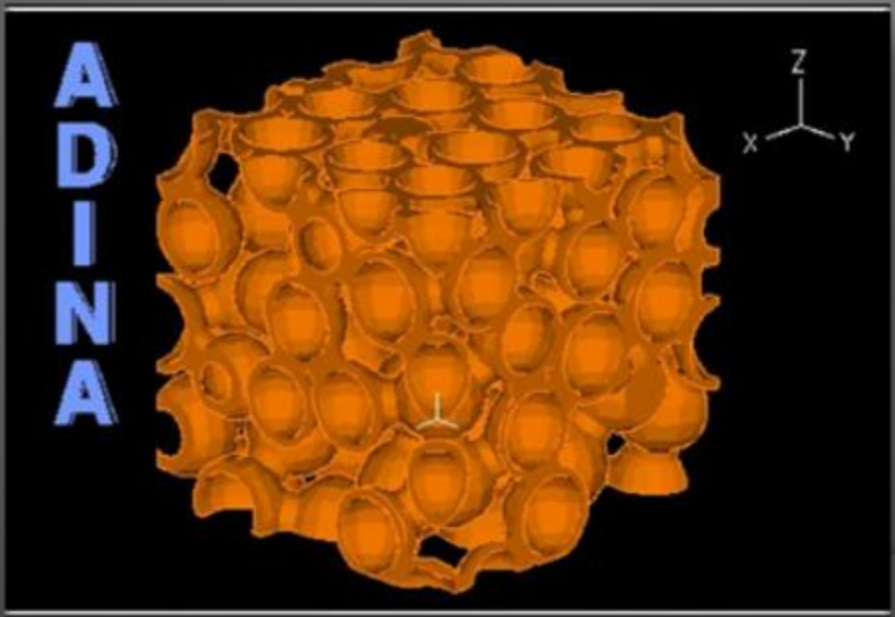
Random Stacking

- Actual foam is a random close-packed (RCP) stacking (Gao et al 2008)
- Several algorithms exist to approximate RCP
  - “Modified Mechanical Contraction Method” shown to be one of best algorithms (Wouterse and Philipse 2006)



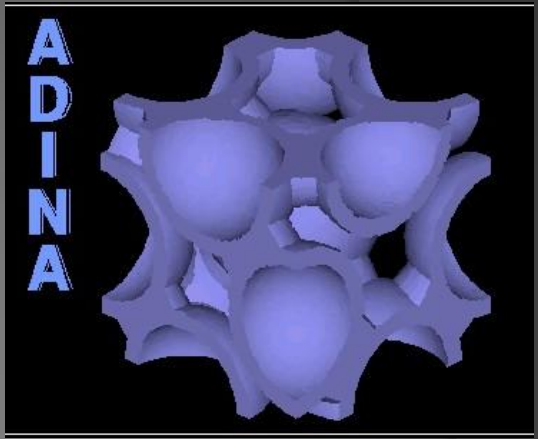
Geometry Generation

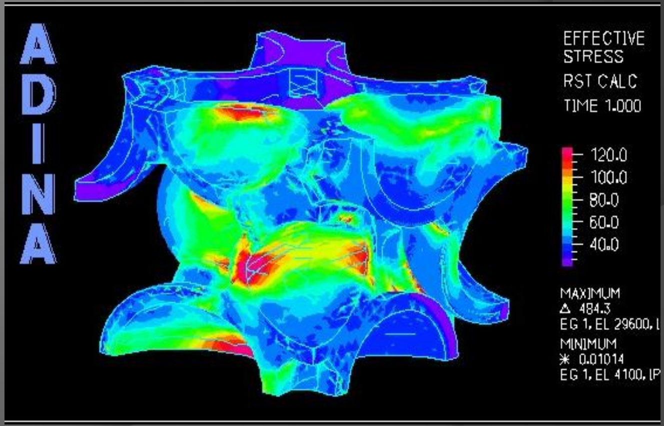
- "Welds" approximated by cylinders between sintered spheres that are within a threshold distance of each other
- Sphere size, wall thickness, weld radius modeled as Gaussian random variables, truncated at zero
- Solid material modeled as bilinear steel



Simulation

- Meshed with second-order tetrahedral elements
- Boundary conditions on -z surface, loading on +z surface
- ~5 mm cube, ~3 million DOFs, ~250,000 elements
  - Takes 3-6 hours on 12-core, 16 GB machine
- Post-processing
  - Stress values from summing exported nodal reaction forces
  - Incremental Poisson's Ratio from averaging exported transverse nodal displacement differentials, divided by applied z-strain
  - Percent of elements yielded by first yield in integration points





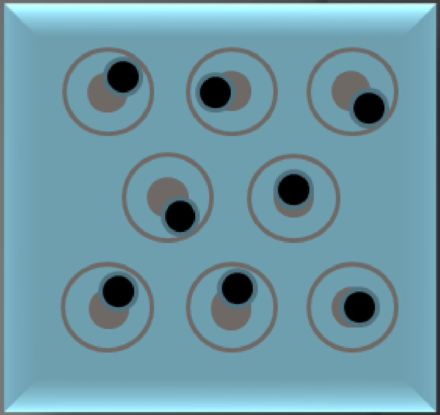
Validation

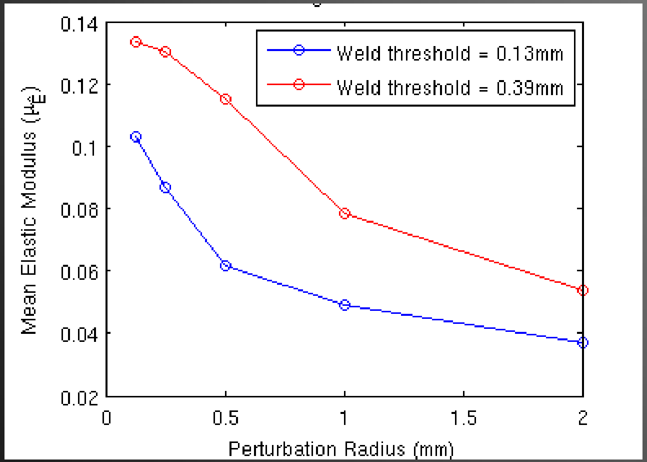
- Agreement in yield stress is shown to be within about 20%
- Material properties of the solid material are not well known
  - Due to sintering process, shell is somewhat porous itself
- Domain should be at least 6-8 sphere diameters to a side for accuracy (Andrews et al 2001)
  - Our simulations thus far are 3-4 sphere diameters to a side due to computational power restrictions

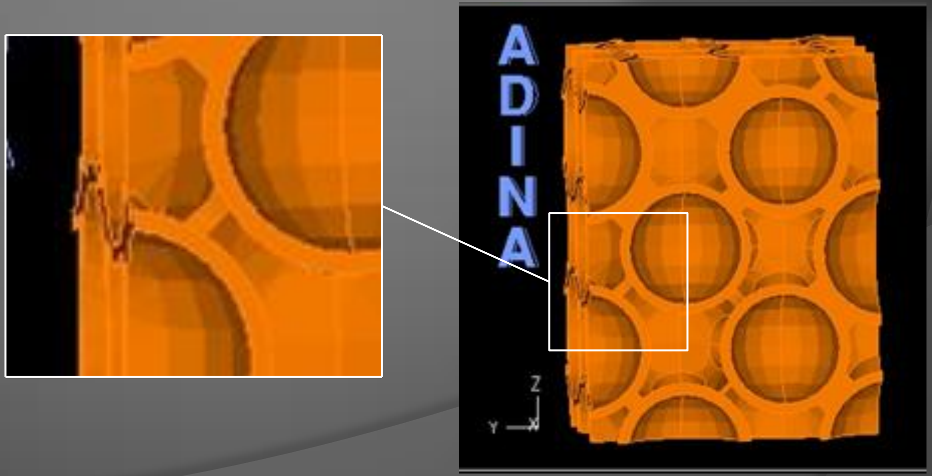
Experimental Reference	Compressive Yield (MPa)	
	Experiment	RCP Simulation
Our experiment	3.6	4.4
Gao et al 2008	3.1	3.6

Test Matrix #1: Elastic Modulus

- Began with face-centered cubic (FCC) initial sphere placement, randomly perturbed within progressively increasing radii
- Also tested increasing the weld threshold 3x
- Tested to 0.01% strain (elastic modulus only)
- Showed that elastic modulus is most strongly dependent upon number of welds present

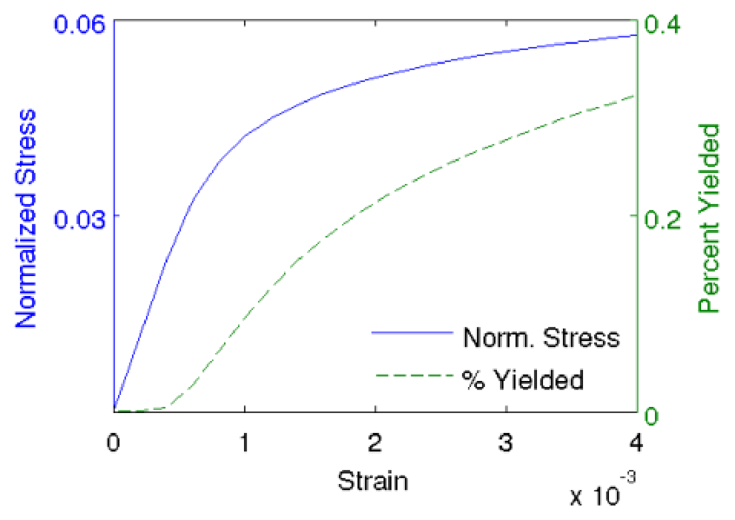


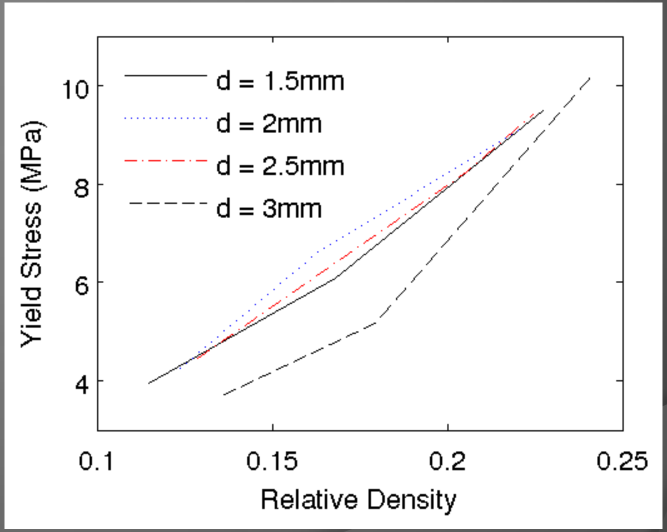




Test Matrix #2: Yielding

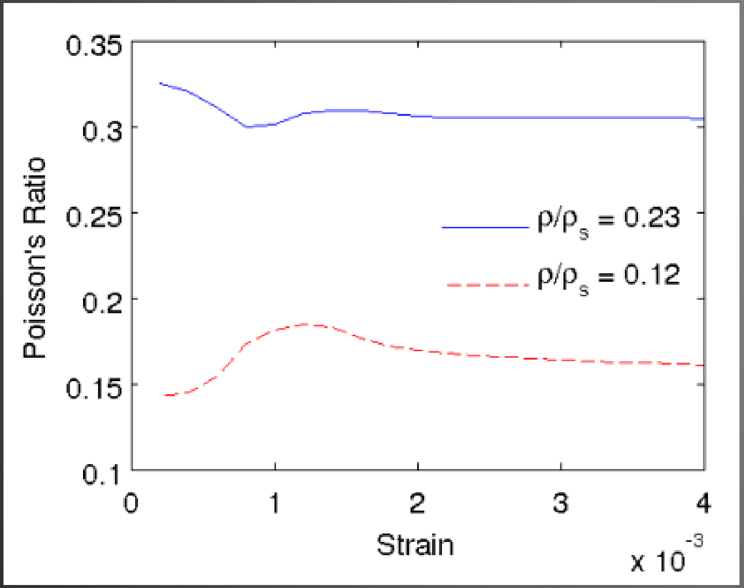
- Varied sphere size and relative density
- Tested to 0.4% strain, securely past yield point
- Yield stress shows dependence on sphere diameter, relative density

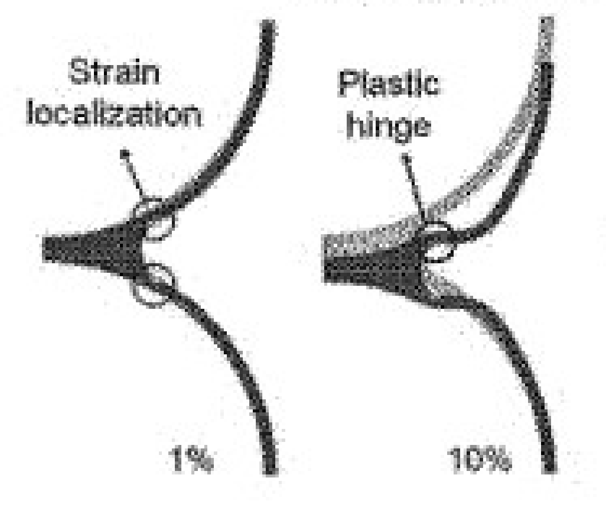




Test Matrix #2: Yielding

- Poisson's ratio shows rapid transition at about 15-20% relative density
  - Caused by plastic hinging effect around welds

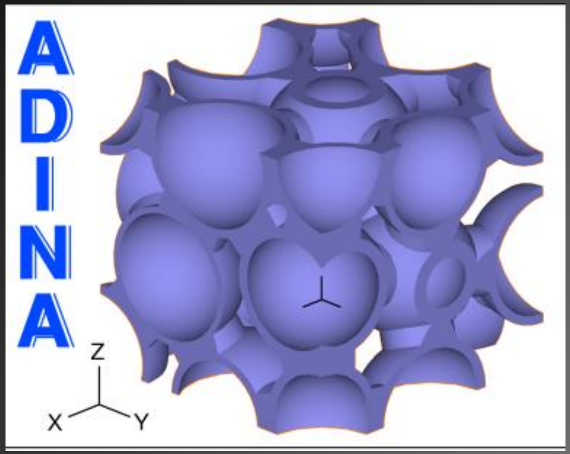


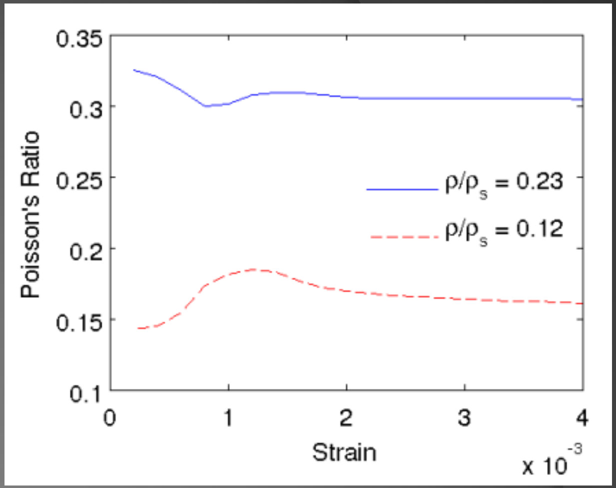


Fallet et al 2007

Conclusions

- A hollow sphere cellular metal may be simulated in a physically accurate manner by means of implementing a random close-packed stacking method
- Compressive yield strength is shown to agree closely within 20% of published experimental results
- Poisson's ratio shows a rapid transition between two different behaviors depending upon relative density and likely upon weld radius as well
- Elastic modulus is most strongly affected by number of welds present in the material





Thank you!
Questions?

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Gao et al 2008