U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

2013 Lightweight Materials Annual Merit Review

Project ID: LM000

Will Joost

Lightweight Materials

Vehicle Technologies Office

Vehicle Weight Reduction

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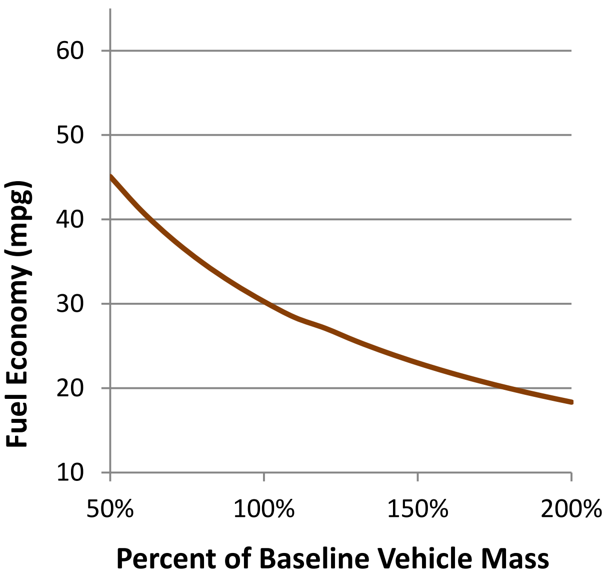
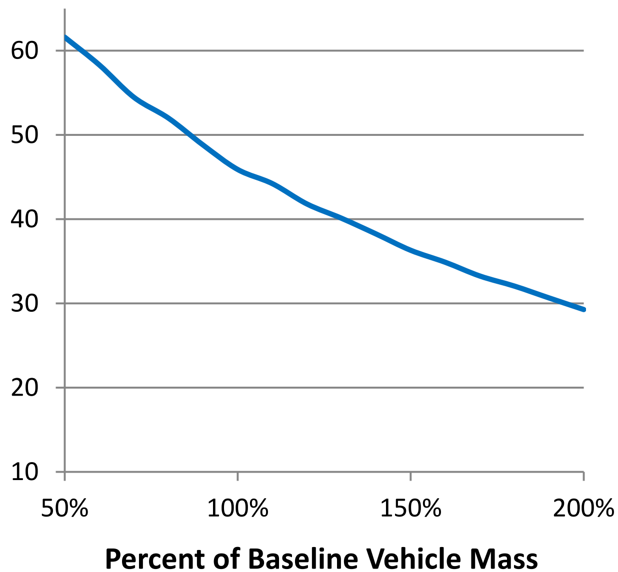
Conventional ICE



NREL 2011

6%-8% improvement in fuel economy for 10% reduction in weight

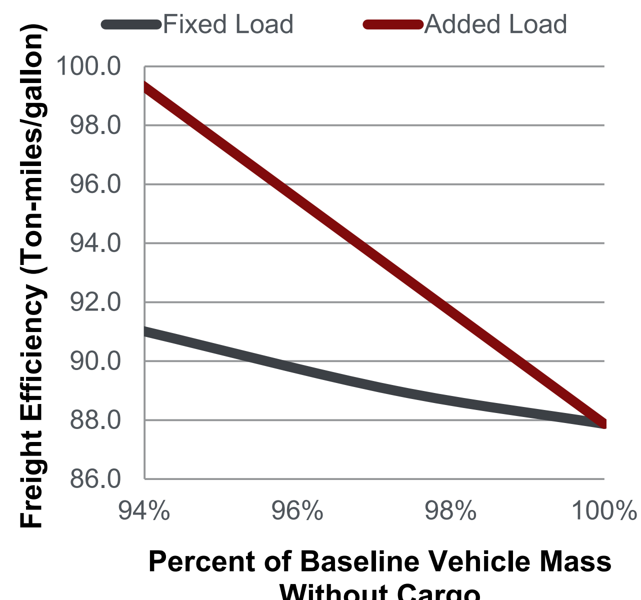
Hybrid/Electric Vehicles



NREL 2011

Improvement in range, battery cost, and/or efficiency

Commercial/Heavy Duty



Ricardo Inc., 2009

13% improvement in freight efficiency for 6% reduction in weight

Trends in Vehicle Weight Reduction

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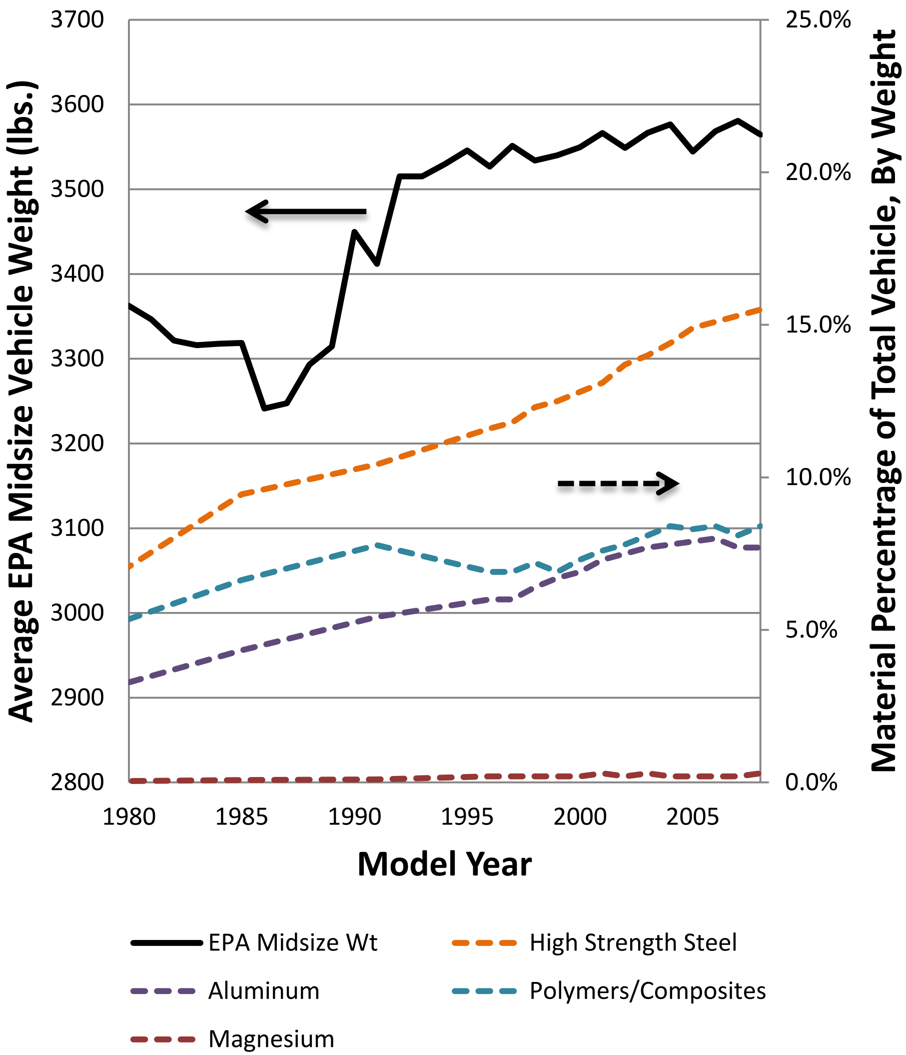
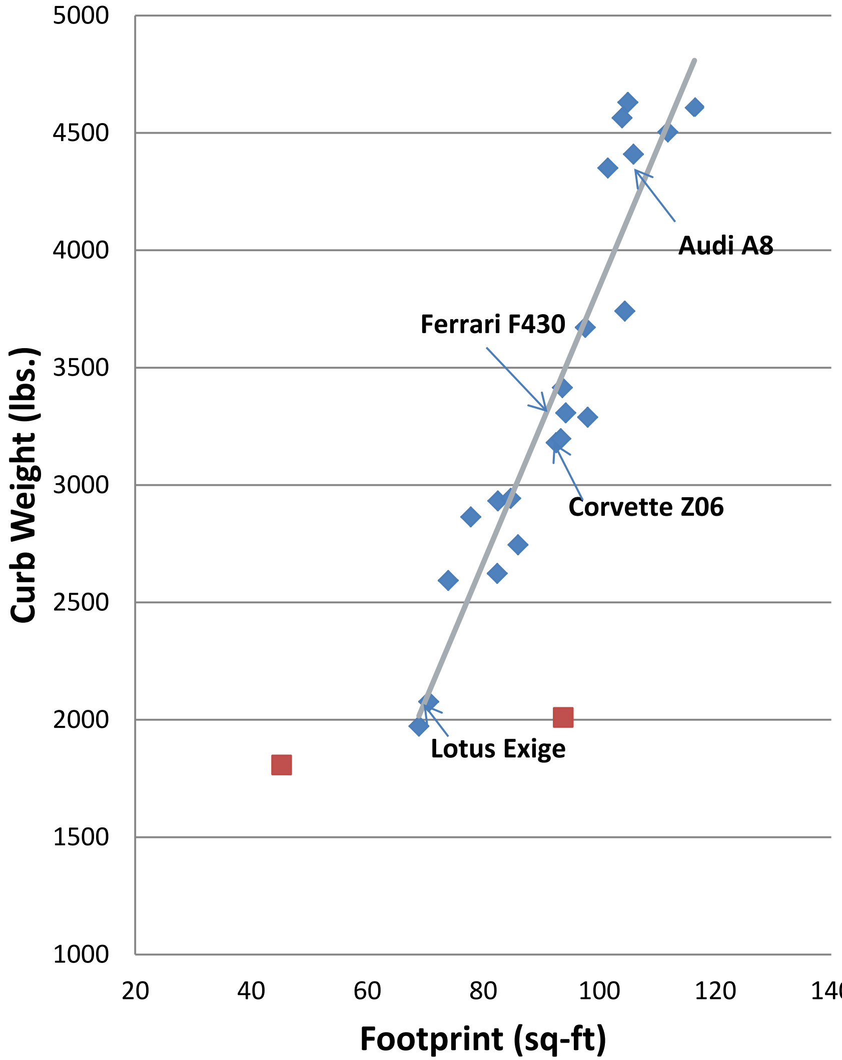
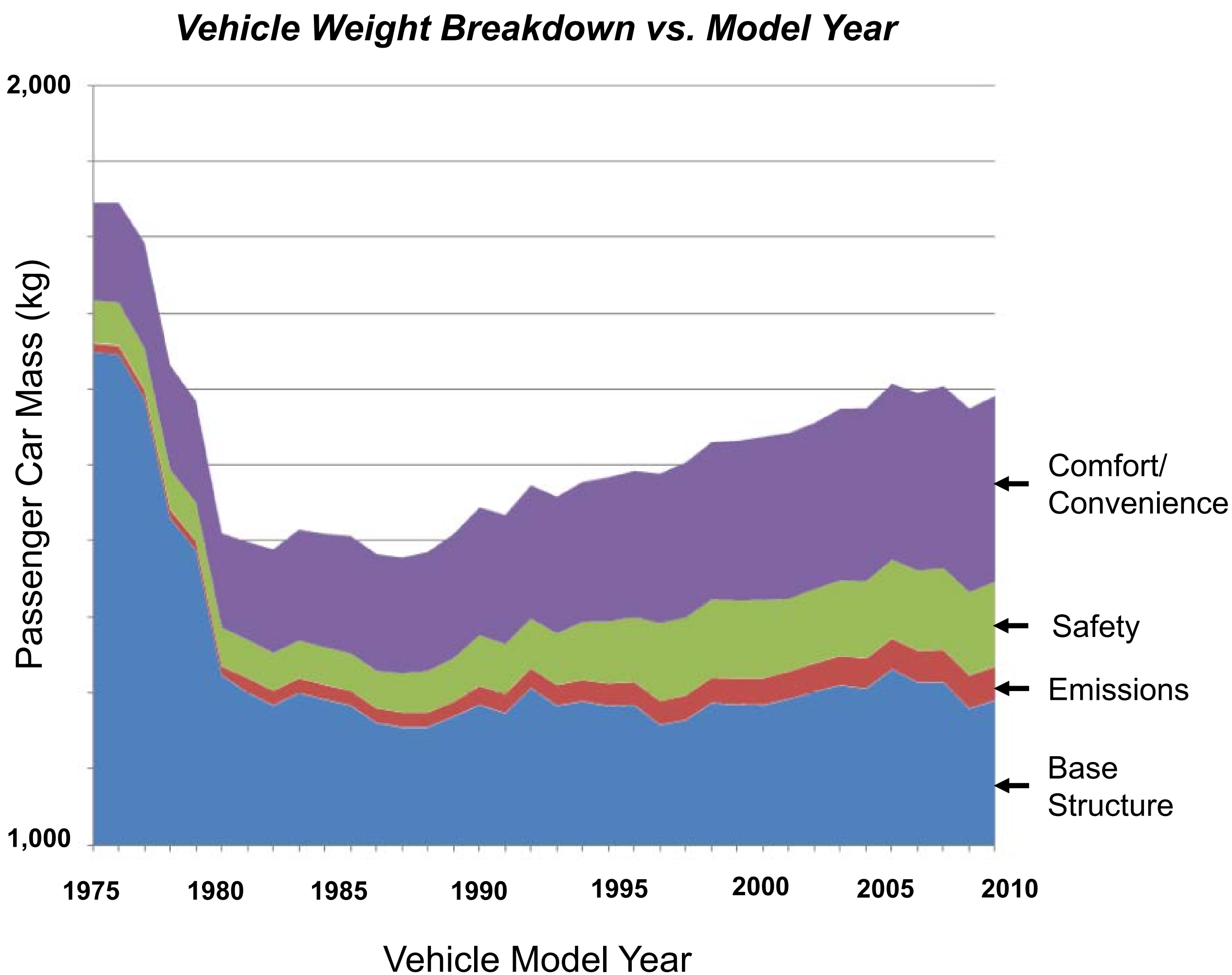
Average Vehicle Weight and Material Content



Vehicle Curb Weight vs. Footprint



Where's the Weight Reduction?



Stephen M. Zoepf "Automotive Features: Mass Impact and Deployment Characterization" MS Thesis, Massachusetts Institute of Technology, June 2011, page 36.

- Comfort, safety, and emissions control have all improved
- Base structure weight has decreased (compounding)
- *System and component weight reduction has been applied to performance rather than total vehicle weight reduction*

Lightweight Materials Program

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Light- and Heavy-Duty Roadmaps

Properties and Manufacturing

- Reducing the cost
  - raw materials
  - processing
- Improving
  - performance
  - manufacturability

Multi-Material Enabling

- Enabling structural joints between dissimilar materials
- Preventing corrosion in complex material systems
- Developing NDE techniques

Modeling and Simulation

- Accurately predicting the behavior
- Optimizing complex processes efficiently
- ICME: Developing new materials and processes

Demonstration, Validation, and Analysis

Lightweight Automotive Materials

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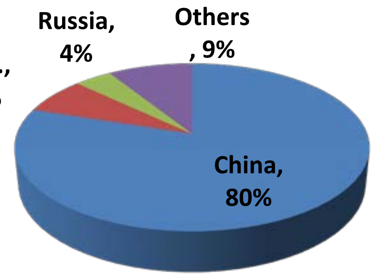
Magnesium Alloys

When it "works" → 40-70% weight reduction

Otherwise → *Cost (~$3-10/ lb-saved)*

- Lack of domestic supply, unstable pricing
- Challenging corrosion behavior
- Inadequate strength, stiffness, and ductility
- Difficult to model deformation behavior



Aluminum Alloys

When it "works" → 25-55% weight reduction

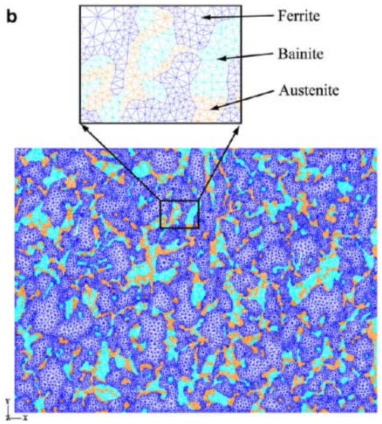
Otherwise → *Cost (~$2-8/ lb-saved)*

- Insufficient strength in conventional automotive alloys
- Limited room temperature formability in conventional automotive alloys
- Difficult to join/integrate to incumbent steel structures

Advanced High Strength Steel

15-25% weight reduction→

- Inadequate structure/properties understanding to propose steels with 3GAHSS properties
- Insufficient post-processing technology/understanding
- What other relevant properties should be considered? Hydrogen embrittlement, local fracture, etc.



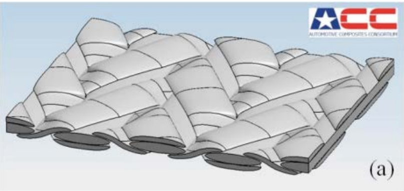
Choi et. al., Acta Mat. **57** (2009) 2592-2604

Carbon Fiber Composites

When it "works" → 30-65% weight reduction

Otherwise → *Cost (~$5-15/ lb-saved)*

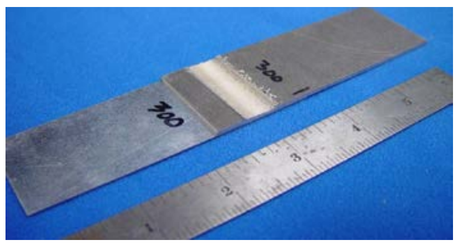
- High cost of carbon fiber (processing, input material)
- Joining techniques not easily implemented for vehicles
- Difficult to efficiently model across many relevant length scales



Multi-Material Enabling

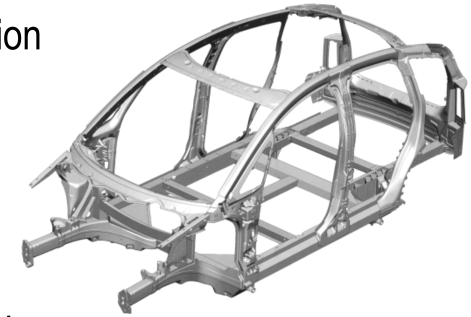
Magnesium Alloys

- Corrosion (galvanic and general)
- Difficulty Joining
  - Mg-Mg
  - Mg-X
  - Riveted Joints
- Questionable compatibility with existing paint/coating systems



Aluminum Alloys

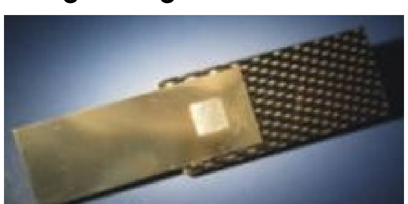
- HAZ property deterioration
- Difficulty joining mixed grades
  - Joint integrity
  - Joint formability
- Difficulty recycling mixed grades



	Mg	Si	Cu	Zn
5182	4.0 - 5.0	< 0.2	< 0.15	< 0.25
6111	0.5 - 1.0	0.6 - 1.1	0.5 - 0.9	< 0.15
7075	2.1 - 2.9	< 0.4	1.2 - 2.0	5.1 - 6.1

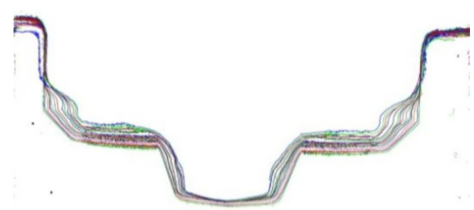
Carbon Fiber Composites

- Corrosion and environmental degradation
- Some difficulty joining
- Questions regarding non-destructive evaluation



AHSS

- HAZ property deterioration
- Limited weld fatigue strength
- Tool wear, tool load, infrastructure



Multi-material Enabling

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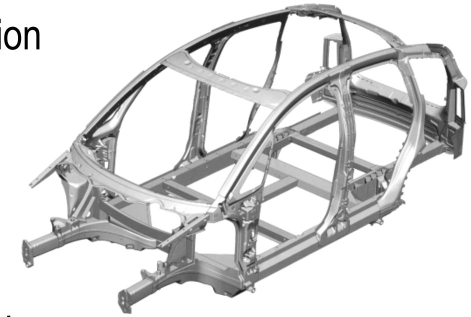

	[illegible]	Si	Cu	Zn
[illegible]	4.0 [illegible]0	< 0.2	< 0.15	< 0.25
[illegible]1	0.5 - 1.0	0.6 - 1.1	0.5 - 0.9	< 0.15
[illegible]075	2.1 - 2.9	< 0.4	1.2 - 2.0	5.1 - 6.1

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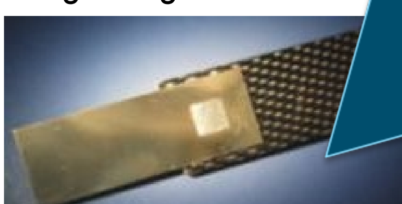


[illegible]SS

- [illegible]Z property deterioration
- [illegible]veld [illegible]tigue strength
- To[illegible]oad, infrastructure

Modeling and Computational Materials Science

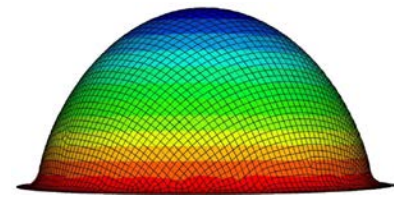
Magnesium Alloys

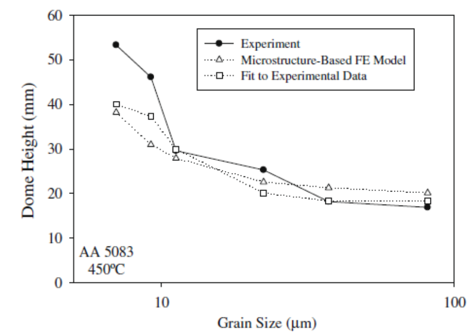
- Complicated deformation in HCP Mg alloys
  - Highly anisotropic plastic response
  - Profuse twinning
- Few established design rules for anisotropy
- Substantial gaps in basic metallurgical data

Q. Ma et al. *Scripta Mat.* **64** (2011) 813–816

Aluminum Alloys

- Basic metallurgical models are well established
- Substantial fundamental data is available
- Useful predictive models established for some conditions
- Truly predictive, multi-scale models are still lacking





P.E. Krajewski et al. *Acta Mat.* **58** (2010) 1074–1086

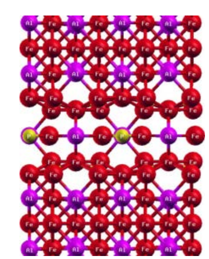
Carbon Fiber Composites

- Insufficient capability in modeling relationships between physical properties, mechanical properties, and ultimately behavior
- Lack of validated, public databases of CFC material properties
- Inadequate processing-structure predictive tools

AHSS

- General lack of understanding on structures, phases, and deformation mechanisms to achieve 3GAHSS properties
- Very complicated structures, phases, and deformation mechanisms likely

N.I. Medvedeva et al. Phys. Rev. B **81** (2010) 012105



Integrated Computational Materials Engineering

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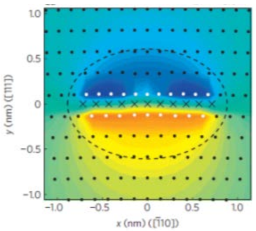
D. Weygand et al., *Mat. Sci. Eng. A.*, **483-484**, 188-190, 2008

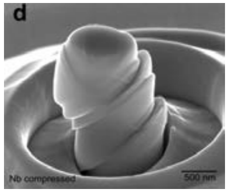
First Principles



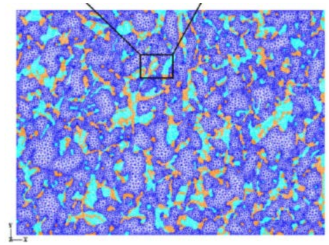
G.P.M. Leyson et al., *Nature Mat.*, **9**, 750-755, 2010

Crystal/Grain Deformation

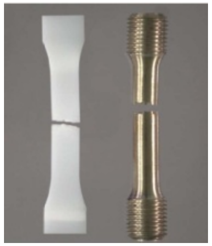
Fine-scale Measurement



Microstructure Performance

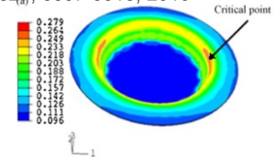


Bulk Measurement

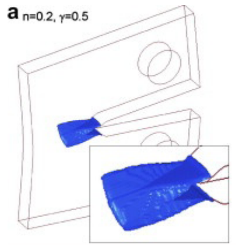


Yield/Hardening

M. Yang et al., *Mat. Sci. Eng. A*, **527**, 6607-6613, 2010

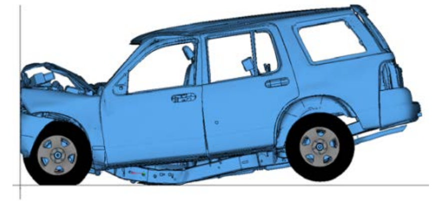


Failure/Fracture



L. Xue & T. Wierzbicki, Int. J. Sol. and Struc. **46**, 1423-1435, 2009

$$1 = (G + H)\sigma_1^2 - 2H\sigma_1\sigma_2 + (F + H)\sigma_2^2 + 2N\sigma_{12}^2$$



http://www.ncac.gwu.edu/research/pubs/NCAC-2012-W-002.pdf

Combined Computational/ Experimental

- Variable set of materials
  - Alloy chemistry
  - Processing-structure
  - *Within scope of selected models*
- Simulate fine-scale behavior, homogenize to higher level models
- Experimental input/validation where appropriate

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