Modeling of cylindrical and pouch cells for crash energy absorption and electric short circuit

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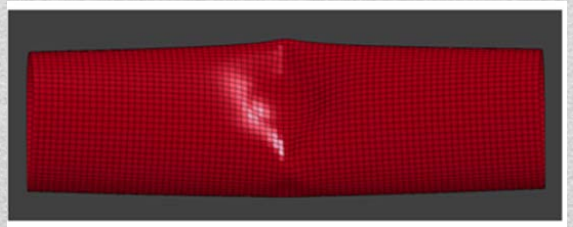


Impact and Crashworthiness Lab (ICL)

- The energy absorption capabilities of prismatic and curved members has been studied at ICL in the three previous industrial consortia
- Limits on material ductility has been studied at ICL for the "Industrial Fracture Consortium", Phase I (2007-2010), and the current Phase II (2011-2013)
- Energy absorption of a jelly-roll is the subject of the ongoing study for the "Battery Modeling Consortium" at ICL in 2011-2013

Relevant Industrial Consortia at ICL

1985-1990 Vehicle Crashworthiness Optimization
Total budget $650,000
14 Participating companies:

Audi	GM
BMW	Opel
Citroen	Peugeot
Chrysler	Porsche
Daimler	Renault
Fiat	Volkswagen
Ford	Volvo

1995-1996 Modeling of Energy Absorption of Honeycomb Barrier
Total budget $150,000
5 Participating companies:

BMW
Cellboned Composite
Ford
Hexel
Mitsubishi Motors

- *Deliverables of the above programs was the computer code CrashCad, its current version, Visual Crash Studio is being used by the worldwide automotive industry*

Relevant Industrial Consortia at ICL, cont.

1995-2000	Collision and Grounding of Ships Total budget $2,600,000 20 Participating companies: American Bureau of Shipbuilding ARCO Marine, Inc Bureau Veritas China Classification Society ClassNK Daewoo Shipbuilding & Heavy Machinery Ltd. Det norske Veritas E3 Tanker Consortium Germanischer Lloyd Hitachi Shipbuilding Co. Hyundai Heavy Industries Co., Ltd. Ishikawajima-Harima Heavy Industries Co., Ltd. Kawasaki Heavy Industries Co. Lloyd's Register Mitsubishi Heavy Industries Mitsui Engineering & Shipbuilding Co., Ltd. A.P. Moller Group (Shipowner and Odense Steel Shipyard Ltd.) NKK Corporation Samsung Heavy Industries Co., Ltd. Sumitomo Heavy Industries, Ltd.

- *The computer software damage, for rapid estimation of the effect of grounding/collision was developed for that project*

Relevant Industrial Consortia at ICL, cont.

1998-2003	Ultralight Metal Body Structure	
	Total budget $1,200,000	
	14 Participating companies:	
	Alcan	GM
	Alcoa	Hexel
	Alusuisse	Honda
	Alulight	Hydro Aluminum
	BMW	Peugeot/Citroen (PSA)
	Cymat	Volvo
	Ford	

- *Deliverables of the consortium was a set of rules entitled "Some Ideas for Car Weightwatchers"*

Relevant Industrial Consortia at ICL, cont.

2007-2013 Fracture of Advanced High Strength Steels
Total budget Phase I $1,300,000, Phase II $ 1,700,000

23 Participating companies:

- Altair (Radioss)
- American Iron and Steel Institute (AISI)
- Arcelor/Mittal Global
- Aperam
- Dassault Systemes SA (Abaqus)
- Engineering Systems International (Pam Crash)
- Ferrari
- GE Global Research
- Hyundai Motor
- LSTC (LS-Dyna)
- Nissan Motors
- Posco Steel
- ThyssenKrupp Steel
- Volkswagen
- Chrysler
- Fiat
- Ford
- GM
- Pratt & Whitney
- PSA
- Shell Oil
- VoestAlpine
- Bettis Atomic Power Lab

- *The deliverable of the consortium would be a complete plasticity and fracture model implemented into ABAQUS, LS Dyna, Pam Crash, and RADIOSS*

Battery Modeling Consortium

Total Support: $625K

- MIT Battery Consortium ($140K/year)
  - Toyota and Volkswagen
- Ford/MIT Alliance ($144K/year)

ICL Team

- Professor Tomasz Wierzbicki
- Dr. Elham Sahraei, Postdoctoral Associate
- Rich Hill, Graduate Student
- John Campbell, Graduate Student
- Joe Meier, Graduate Student

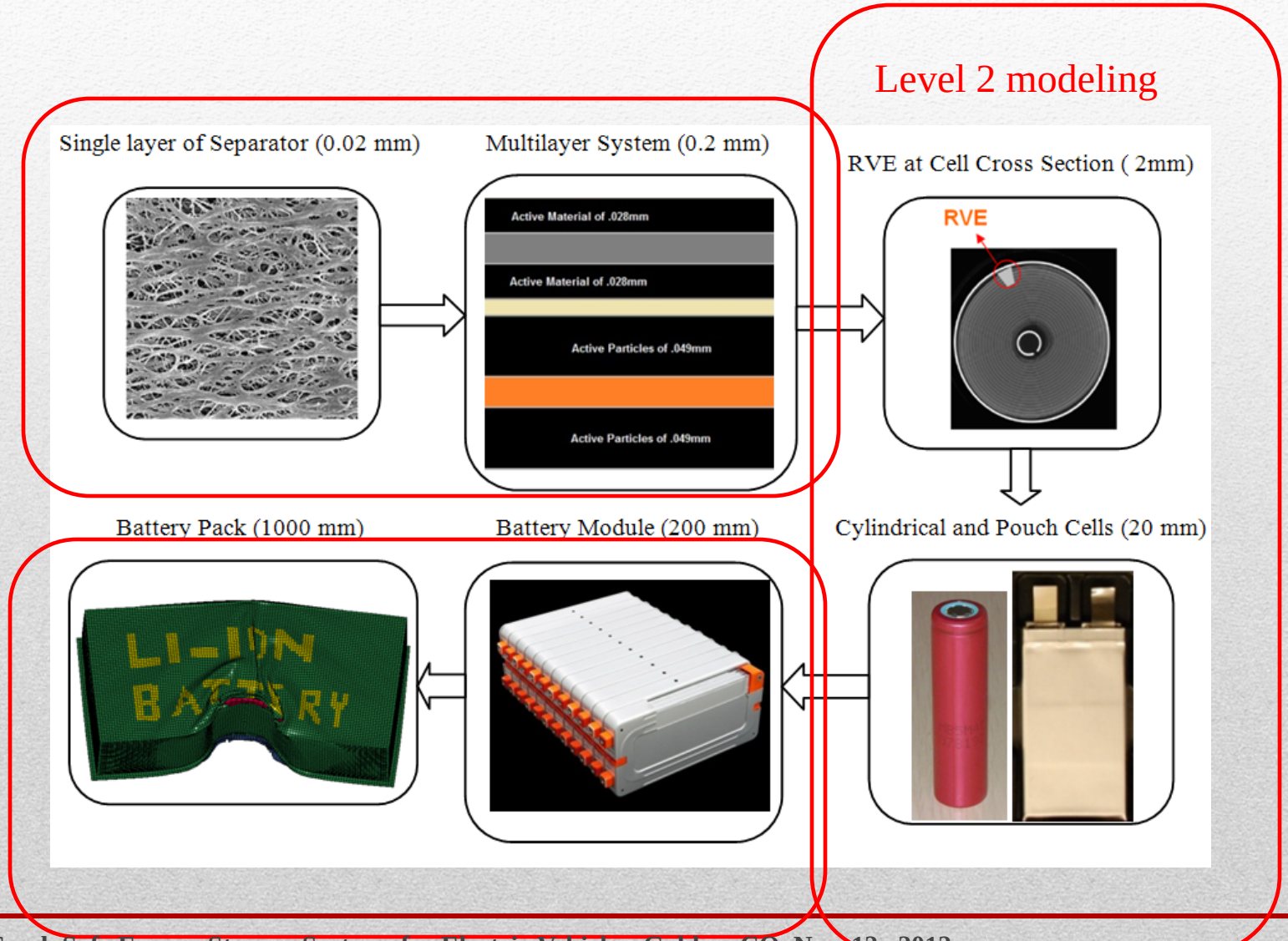
Collaborators

- Ernst Mach Fraunhofer Institute, Freiburg, Germany
- A123 systems in Waltham, MA
- Exponent, Menlo Park, CA

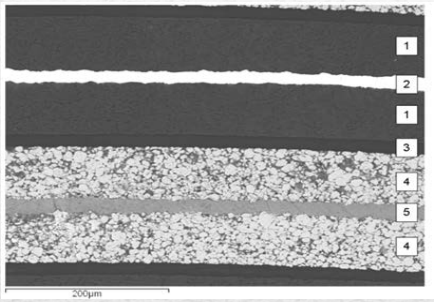
Objective and Scope of MIT Research

Cell Level **Current Research**	**Development of constitutive model from experiments and parallel FE simulation to be valid for all possible loading conditions**
Module Level	Apply the results of cell level model to predict response of battery module under typical loading conditions for electric short circuit detection and energy absorption
Battery Pack Level	Assemble several modules into the battery pack with a housing in order to integrate it with a full vehicle model (in collaboration with industrial partners)

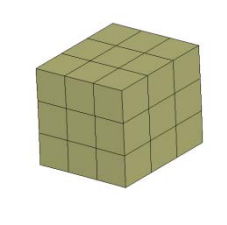
Scale of Present Modeling



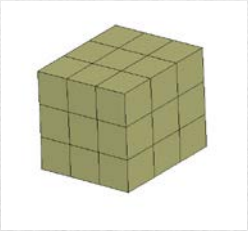
Modeling Concept



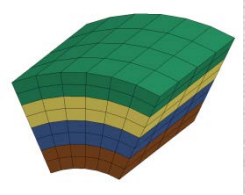
Homogenous Isotropic RVE



Homogenous Anisotropic RVE



Structural Layeres

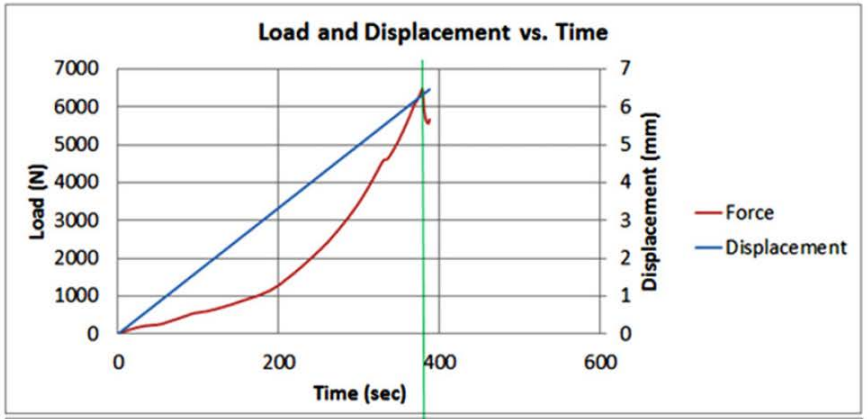


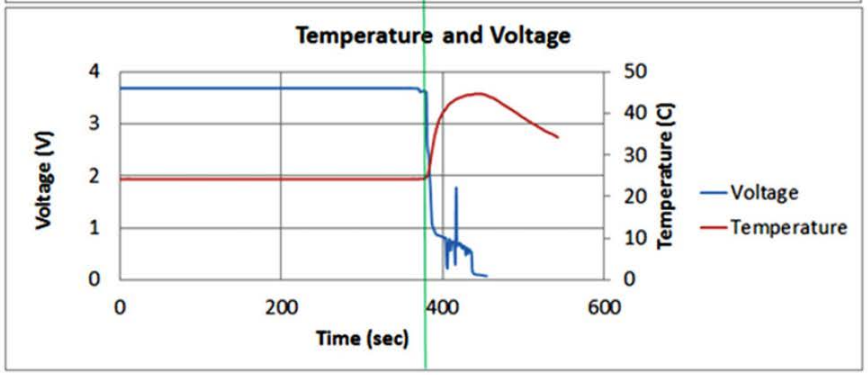
Description of Test Equipment at MIT

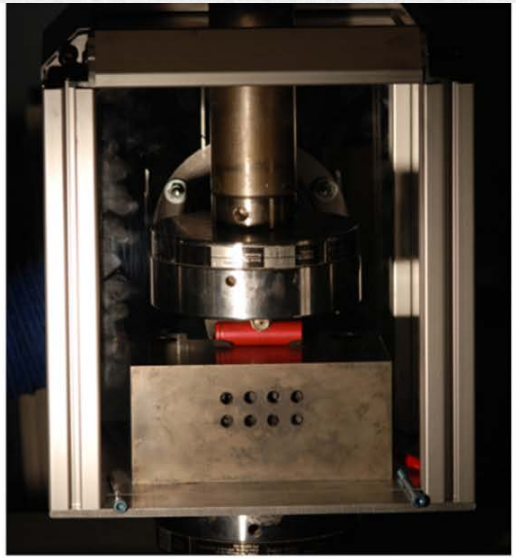
- 200 kN MTS Loading Frame, 10 kN Load Cell
- Tabletop Instron Machine, 100N, and 5KN load Cells
- Digital Multimeter, Voltage accuracy of 0.3%
- Omega HH176 Thermometer, accuracy +/-0.05%
- Environmental Chamber with exhaust fan
- Digital Image Correlation for displacement and strain

Example1 Lateral Indentation of the Cell

- Energy absorption is limited by failure of jellyroll

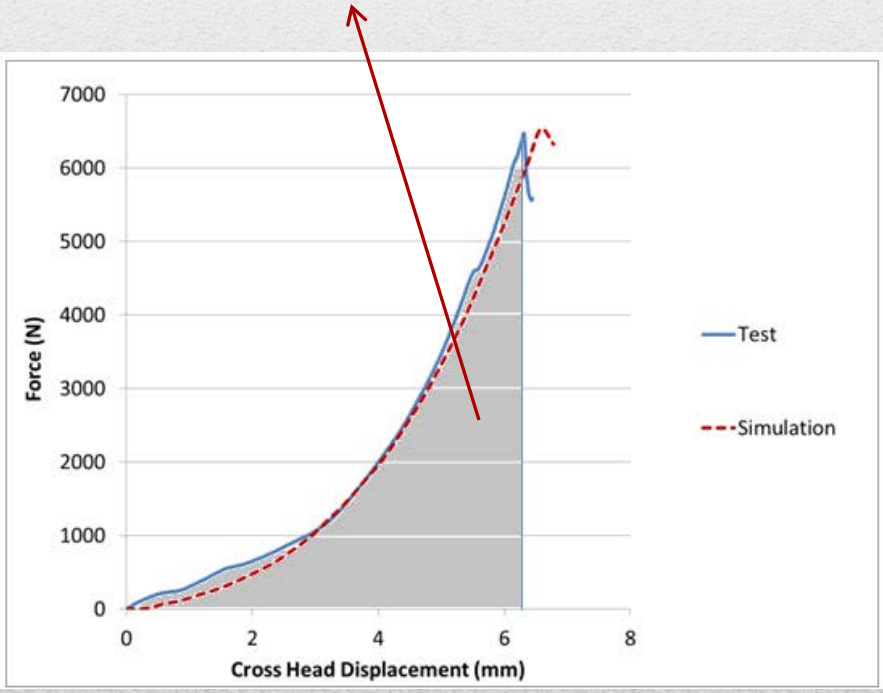


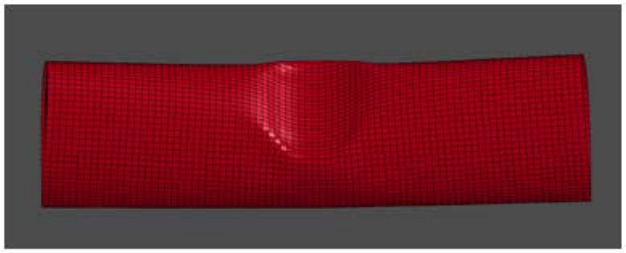




Simulation, Indentation by a Rigid Rod

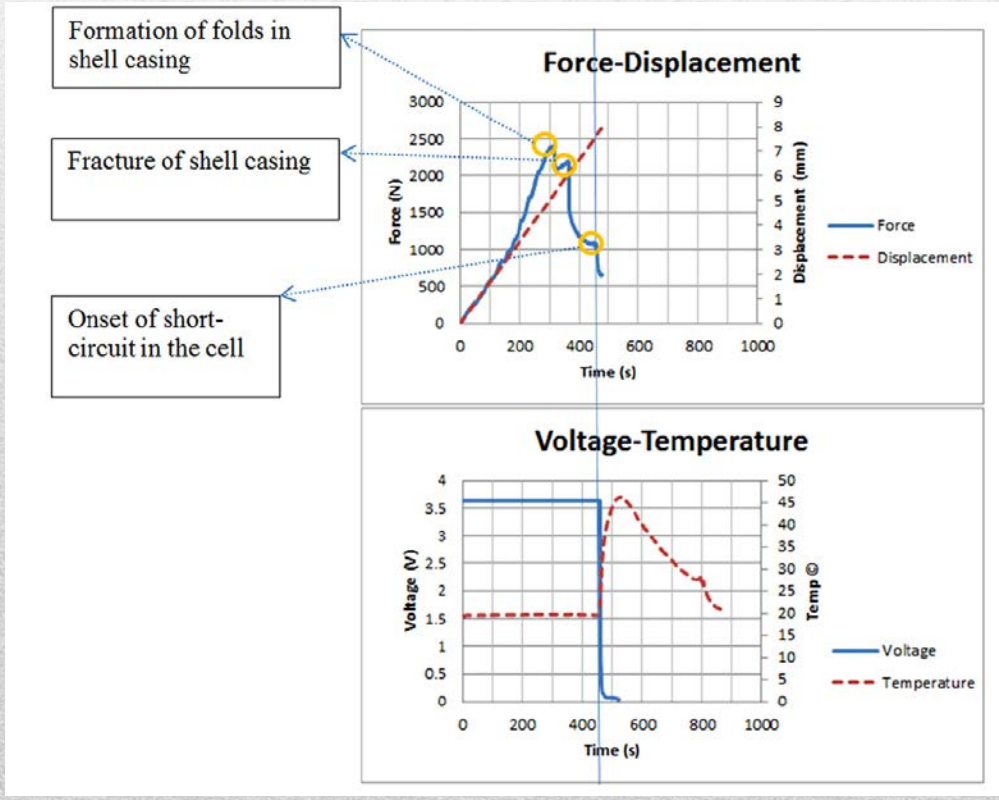
- The peak force from simulation 6532 N at 6.6 mm (in test 6469 N at 6.3 mm)
- Energy absorption is limited by short circuit (failure of jellyroll)
- Energy absorbed: 268 J/Kg (0.268 J/gr)

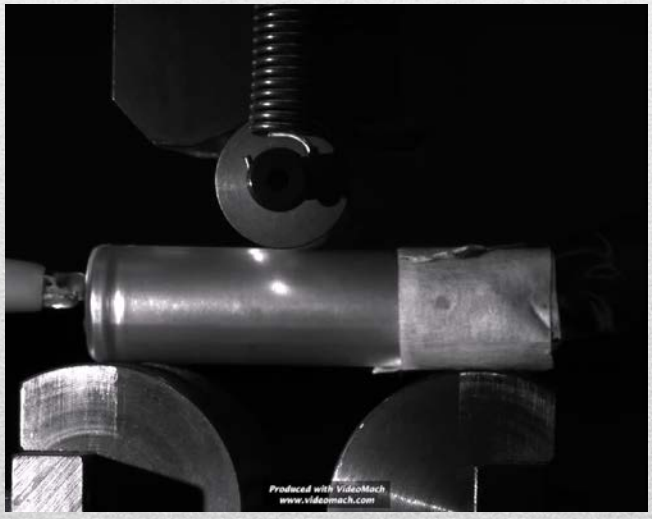




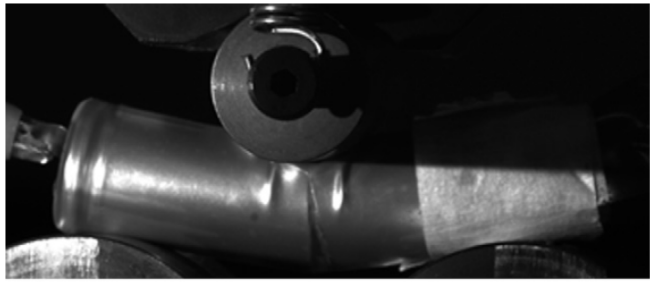
Exampe 2, Three-point Bending

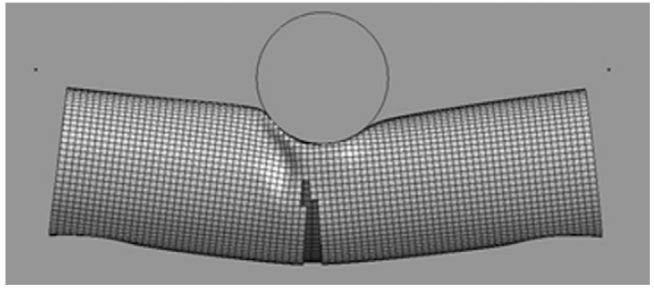
- Energy absorption is limited by fracture of shell casing followed by failure of the jellyroll



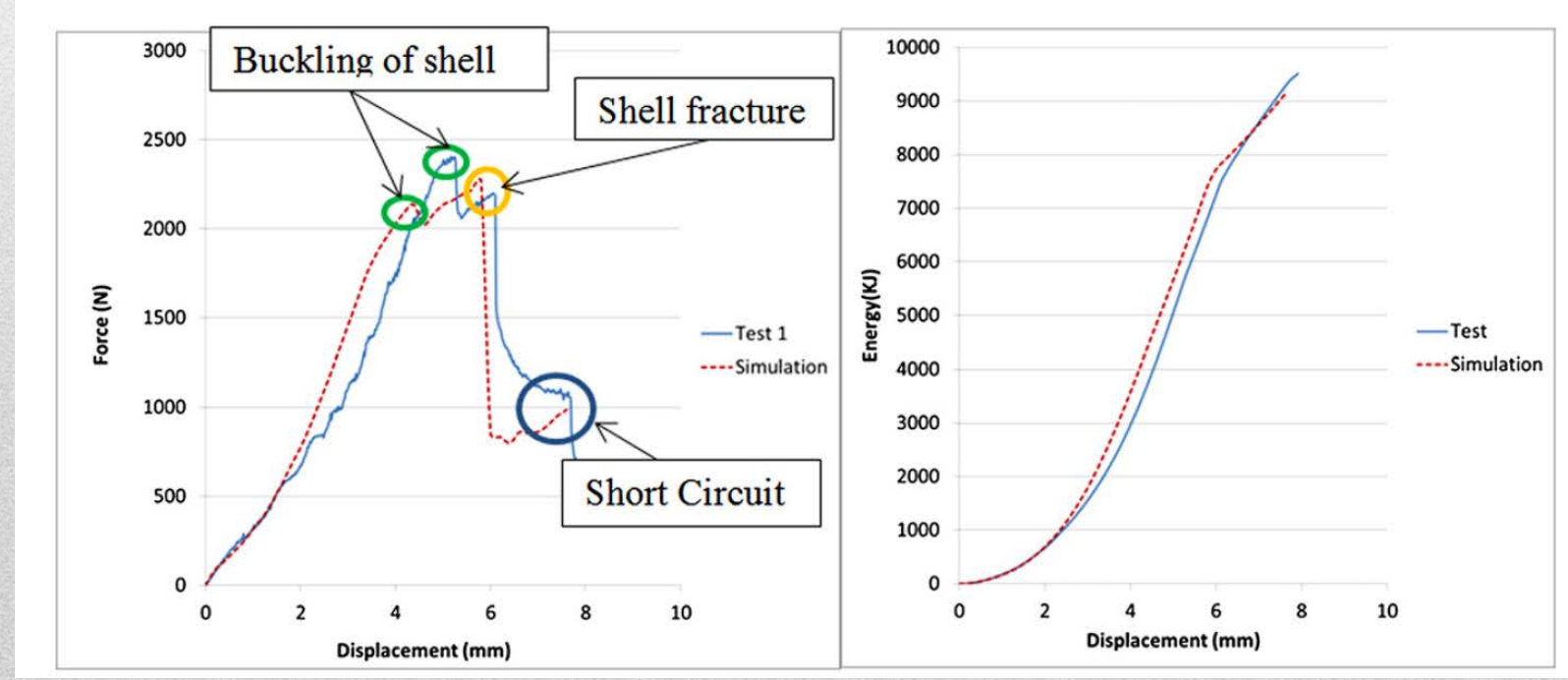


Comparison, 3-point Bending

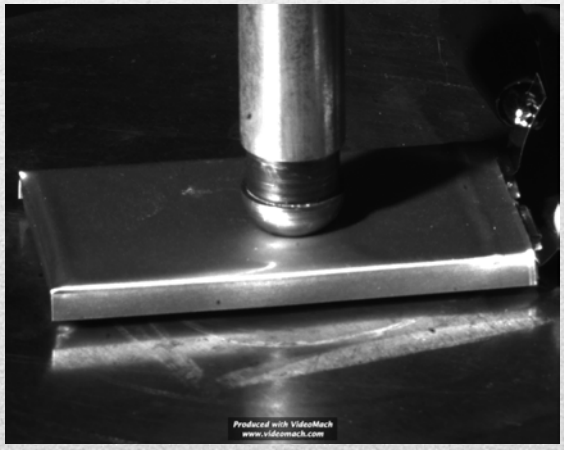




- Buckling of the shell, predicted
- Shell fracture, predicted
- Short-circuit can be expected from level of tensile stresses, but not a drop in force

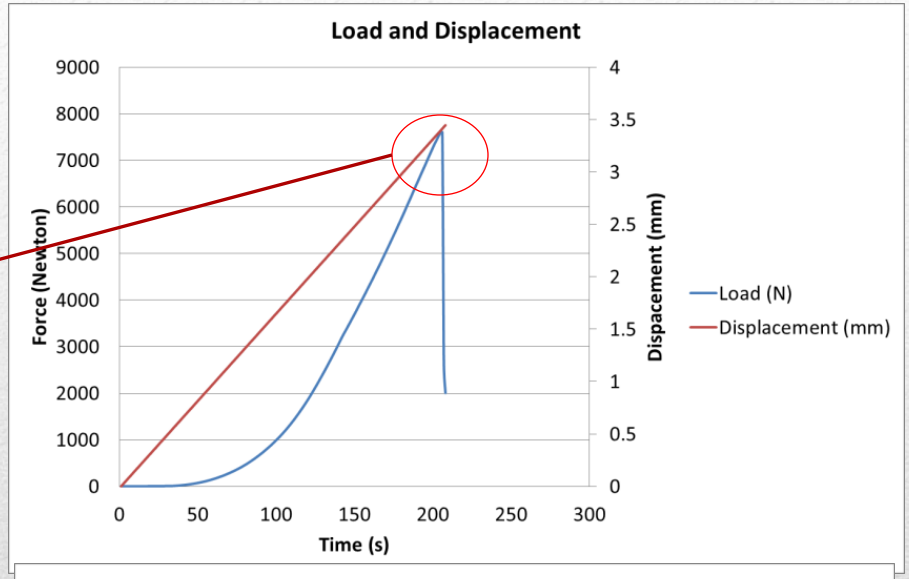


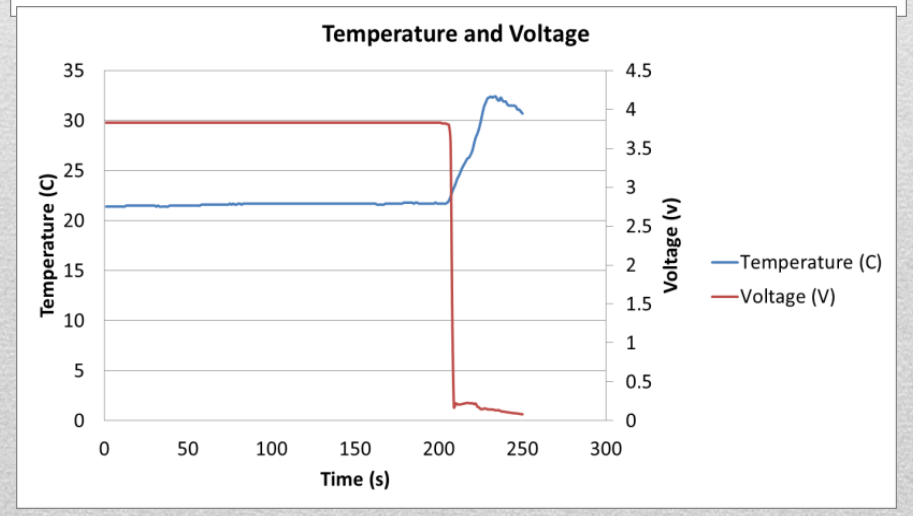
½ inch Hemispherical Punch Tests



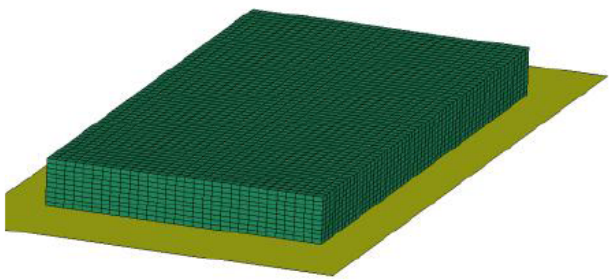
Measured Load, Displacement, Voltage, and Temperature

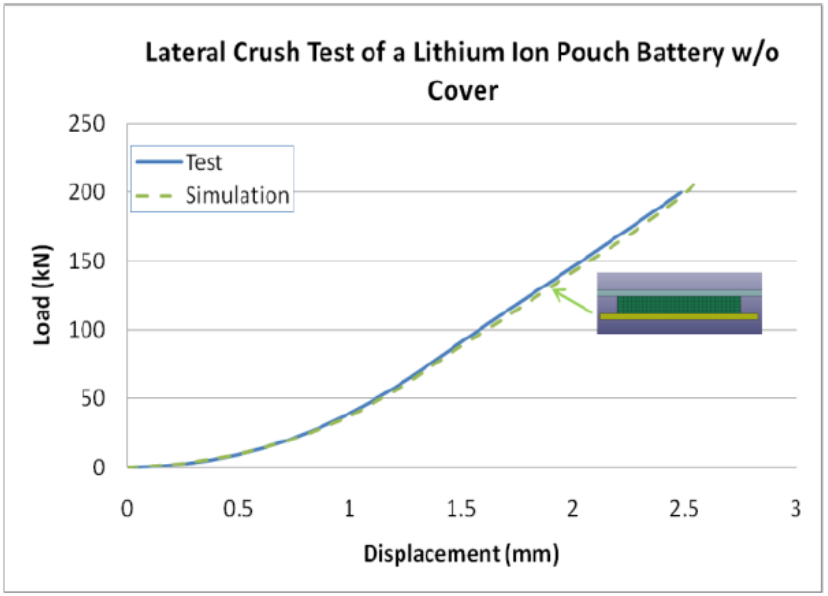
Detecting Point of Short-Circuit





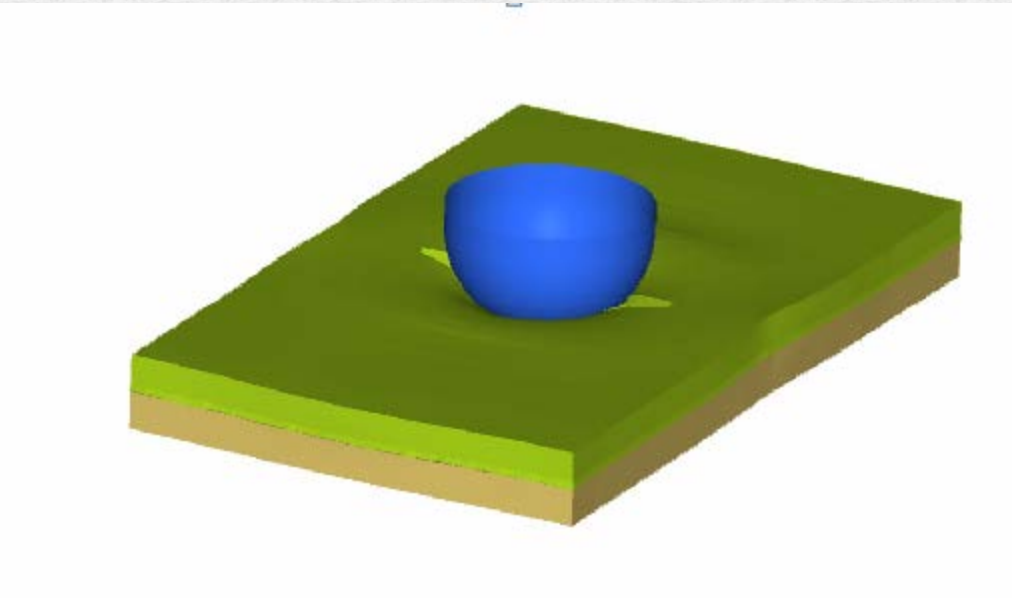
Simulation of Lateral Crush between Two Flat Plates



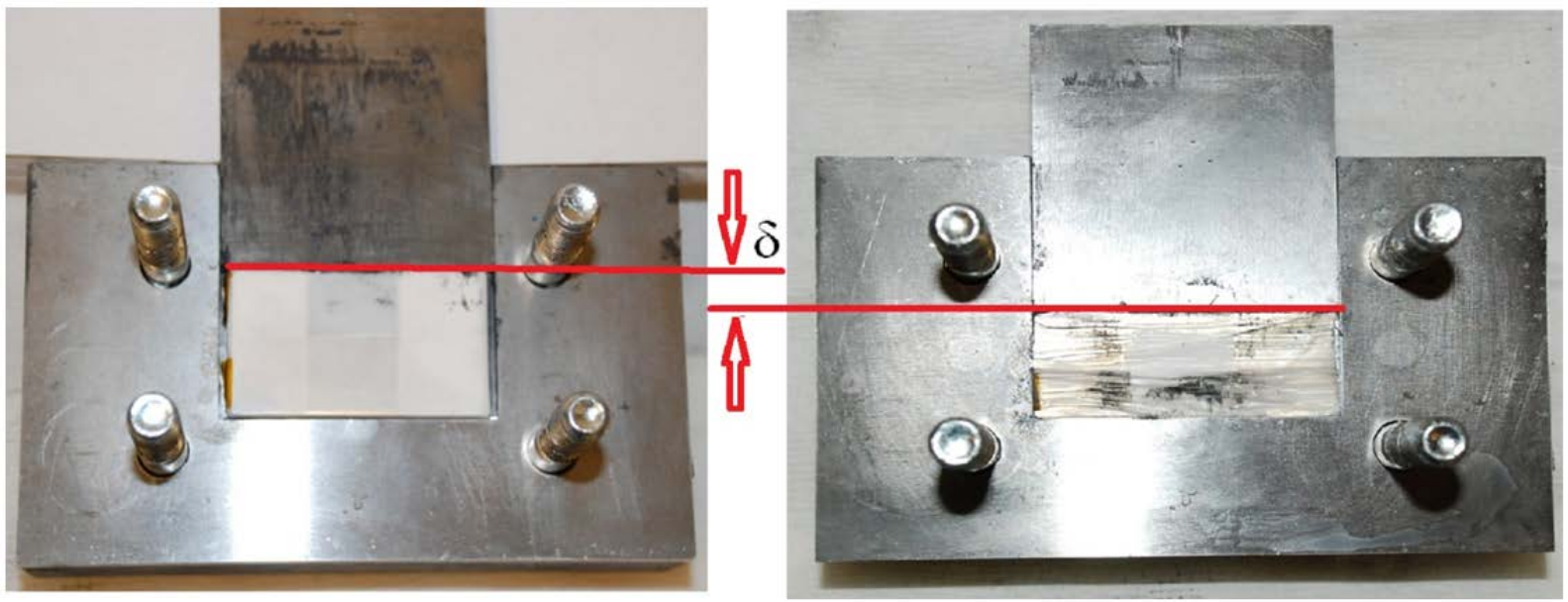


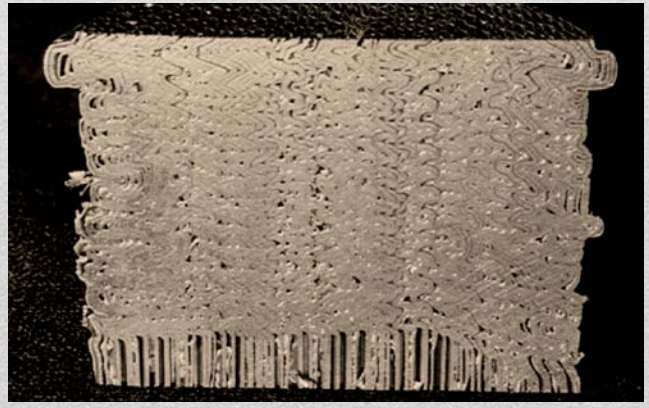
Finite Element Model of the Cell (left) and Comparison of Load Displacement Curve from Simulation to the Test (right)

Anisotropic Modified HoneyComb Model

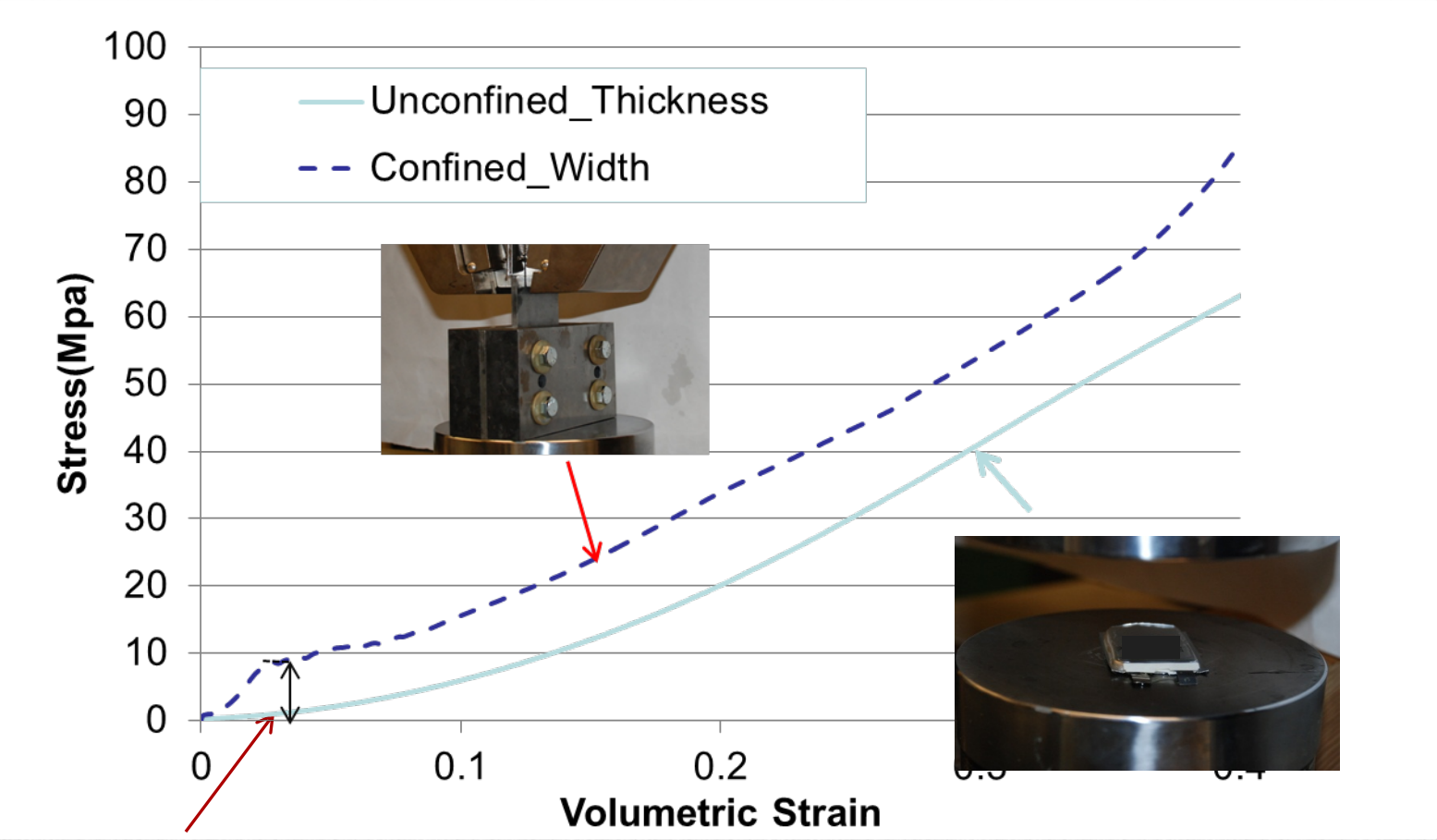


Confined Compression Test



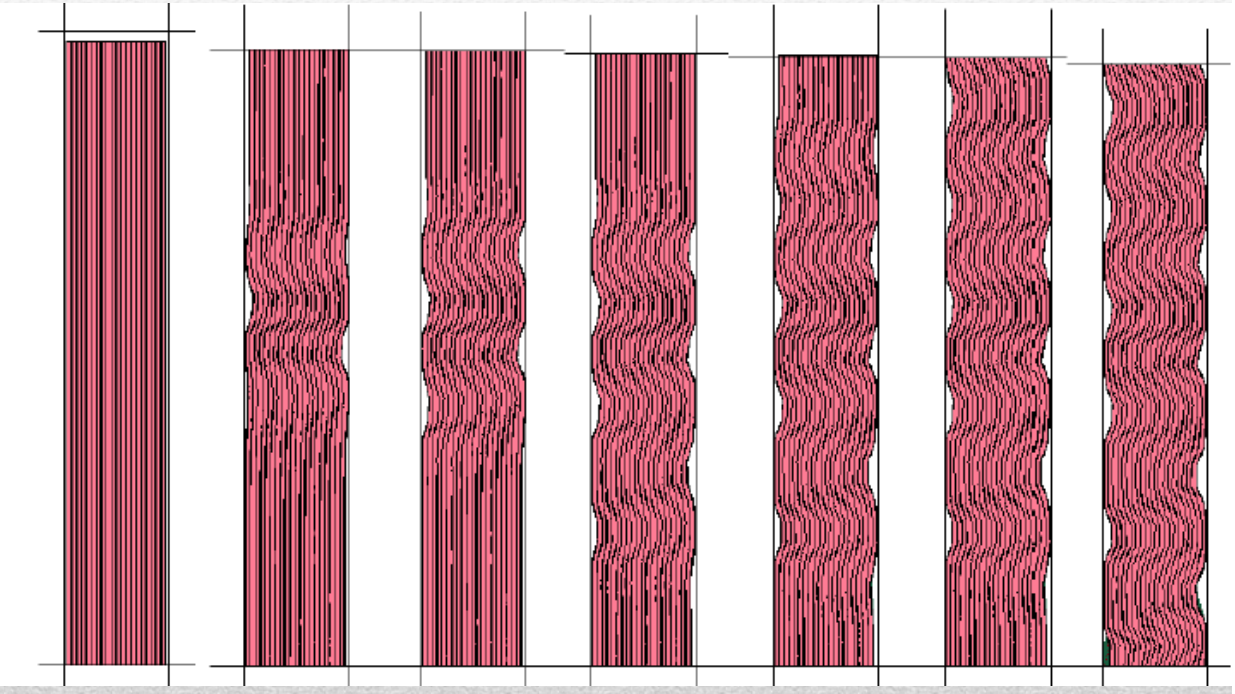


Confined vs Unconfined Experiments on Uniaxial Strain Compression



Contribution of foils

Confined Compression, Deformation Mode (FE simulation)

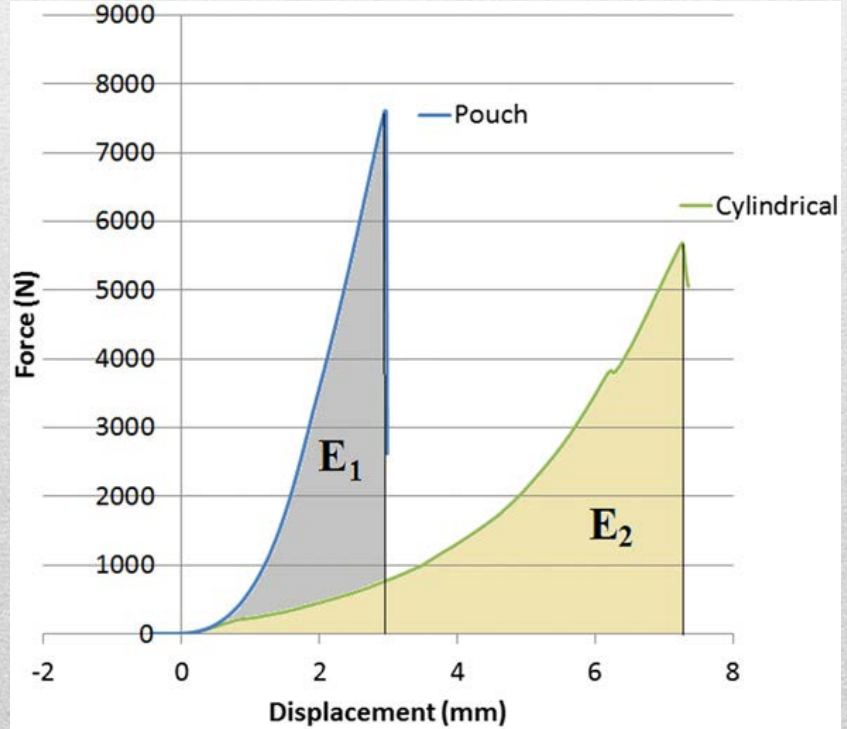


Confined Compression of the Cell in Width Direction Showing Development of Multiple Buckles

Discussion,

Relative merits of pouch versus cylindrical cells

- One measure of comparison to calculate/measure the amounts of energy absorbed by the cells up to the onset of short-circuit



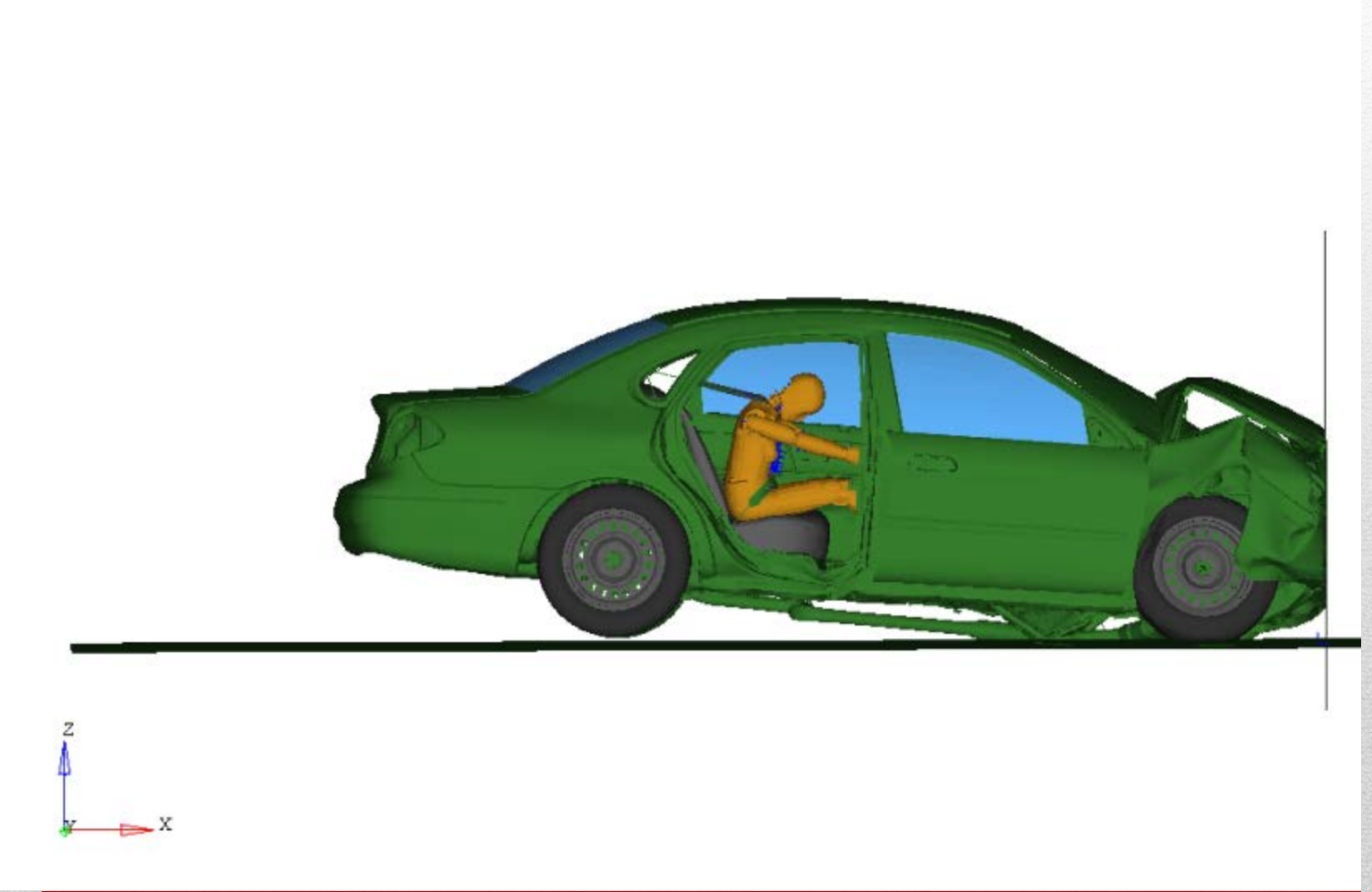
Similar Chemistry

Cylindrical Capacity: 2300mAh

Pouch Capacity: 740mAh

Modeling Battery Pack

Full Vehicle Integration



Energy Absorption of Battery Packs

- Components of the Battery Pack Participating in the Energy Absorption
  - Housing of the battery pack (sheet metal, composite, polymer)
  - Modules (trays, cells, heat sinks, accessories)
  - Cell (jellyroll, shell casing)

- Mechanisms of Energy Absorption
  - Bending and membrane plastic deformation of metal shell casing
    - Energy absorption capacity of metal components is limited by fracture
    - Higher ductility improve energy absorption
  - Compression and shear deformation of the jellyroll
    - Energy absorption capacity of the jellyroll is limited by failure of jellyroll and delamination

How to Improve Energy Absorption

- Failure of the jellyroll is a limit to its energy absorption
- Our models show that this failure is controlled by tensile strength of jellyroll
- To delay tensile failure:
  - Increase strength of binder, ductility of Al, and Cu foils
  - Improved integrity for the separators

- Fracture of battery pack housing
  - Design of housing to prevent fracture and failure of connections