Kinking and folding across materials and scales: fundamental mechanisms for shock energy absorption in transports

Nicolas Feld

PSA Peugeot-Citroën

Outline

- Context and aim
- Plastic folding of metal tubes
- Fragmentation of laminates
- Perspectives

Context

- Protecting occupants against crush

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  - intrusion (survivable space)

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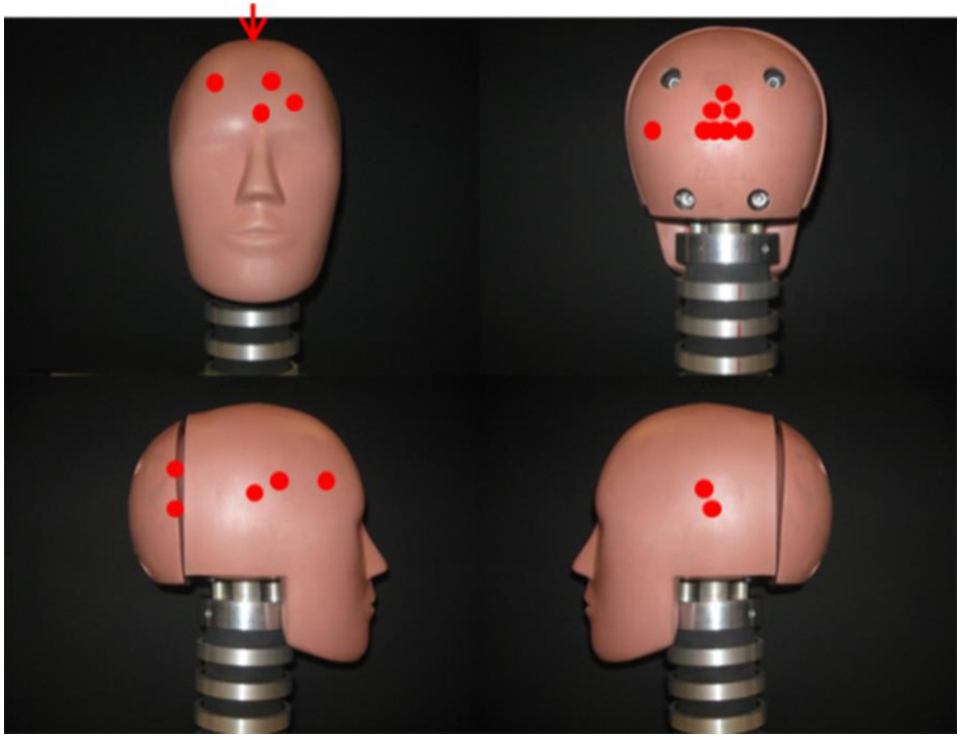
  - intrusion (survivable space)
  - accelerations (biomechanics)



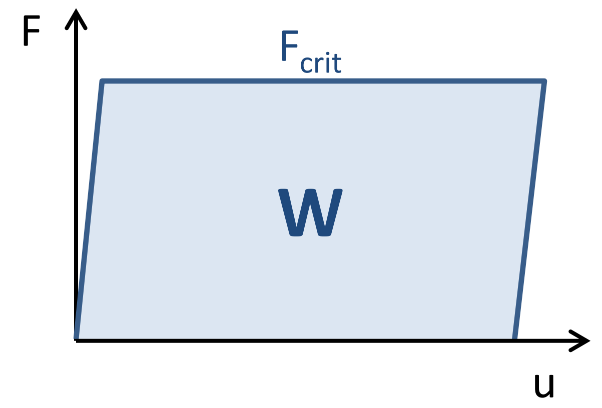
A. Post and T. B. Hoshizaki, *Rotational acceleration, brain tissue strain, and the relationship to concussion*, J Biomech Eng 137 (3), 2015

Context

- Protecting occupants against crush
  - intrusion (survivable space)
  - accelerations (biomechanics)
  - overaccidents (rebounds)

Aim

- In an almost functional analysis, the ideal shock absorber would display
  - Maximum energy absorbed
  - No stress overshoot
  - No elastic recovery



… and would contribute to the rest of the structural behavior in normal situations while minimizing volume, mass, and total cost

Aim

- Question: which physical mechanisms allow for such a behavior?

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Plastic folding of metal tubes

- Principle:

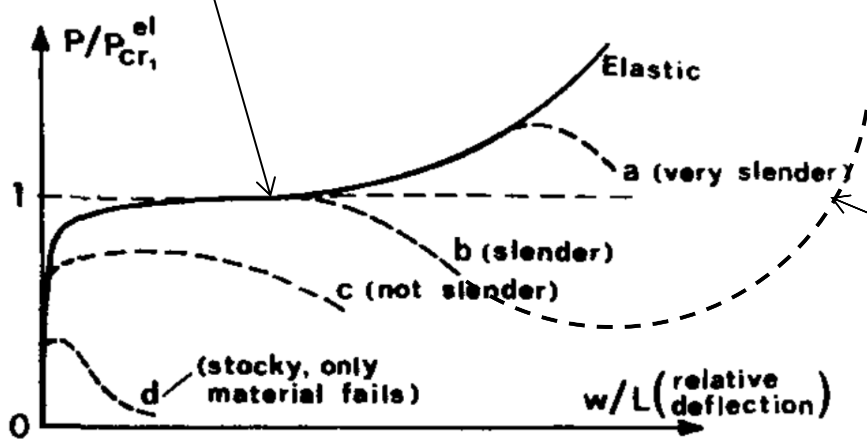
S. Salehghaffari et al., *Attempts to improve energy absorption characteristics of circular metal tubes subjected to axial loading*, Thin-Walled Structures 48, 2010

Plastic folding of metal tubes

- Mechanisms and limits
  - Local geometric instability in the elastic-viscoplastic regime + compaction

$$M\left(w'', \dot{w}''\right) + P\left(w - w_0\right) = 0$$

negative acoustic tensor (localization)



stress recovery (compaction and conjugate buckling)

Z. P. Bazant and L. Cedolin, *Stability of structures: elastic, inelastic, fracture, and damage theories*, Oxford Engineering Science, 1991

Plastic folding of metal tubes

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  - Global geometric instability!

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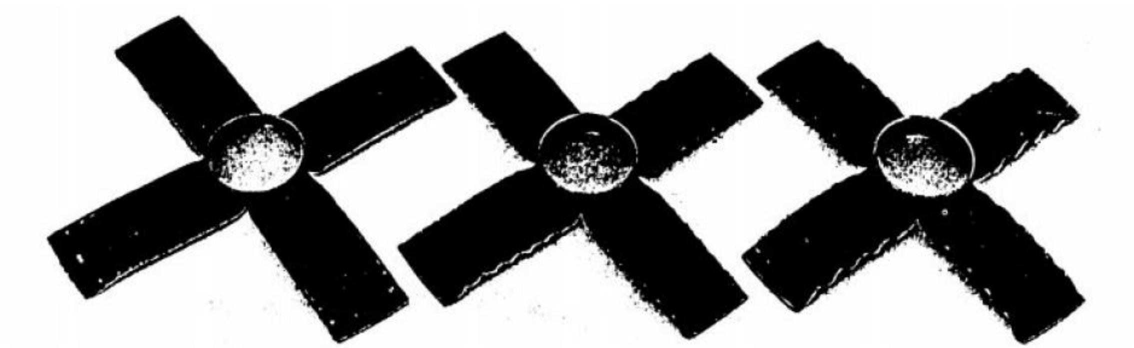
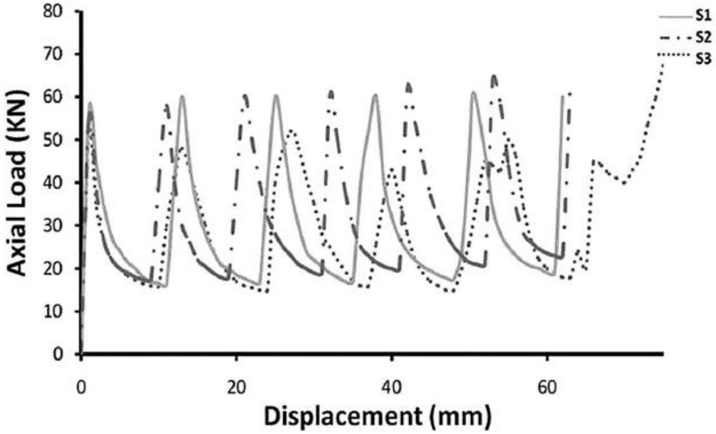


S. R. Reid, *Plastic deformation mechanisms in axially compressed metal tubes used as impact energy absorbers*, Int J Mech Sci 35(12), 1993

Plastic folding of metal tubes

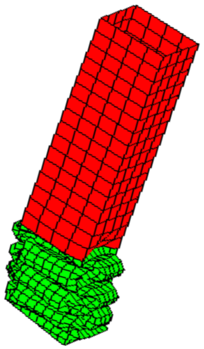
- Mechanisms and limits
  - Local geometric instability in the elastic-viscoplastic regime + compaction
  - Global geometric instability!
  - Material instability (splitting)!
  - Peak load (limited SEA)!

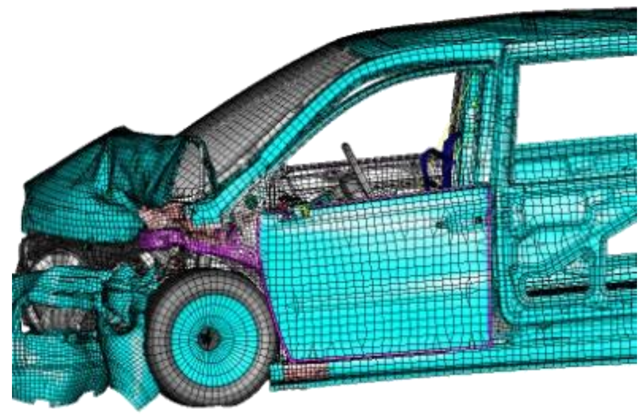


F. Mokhtarnezhad et al., *Improving the crashworthiness characteristics of cylindrical tubes subjected to axial compression by cutting wide grooves from their outer surface*, Int J Crashworthiness 14(6), 2009

Plastic folding of metal tubes

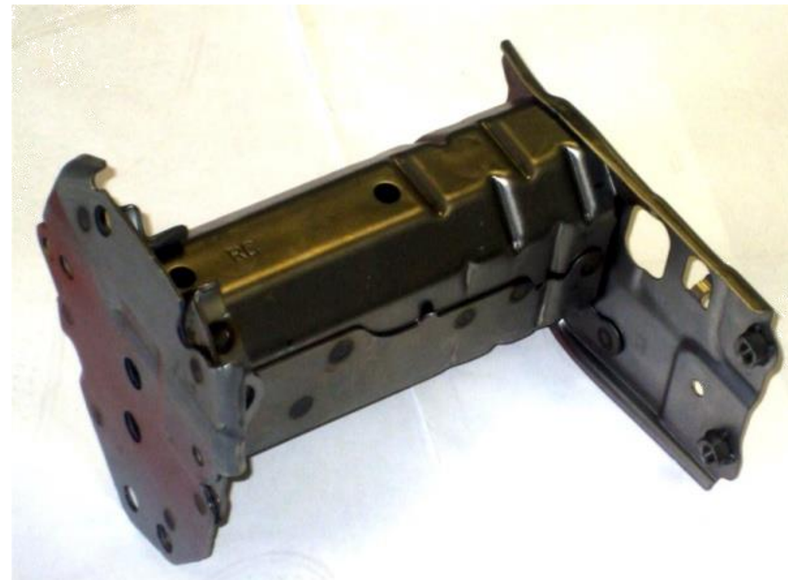
- Mechanisms and limits
  - Local geometric instability in the elastic-viscoplastic regime + compaction
  - Global geometric instability!
  - Material instability (splitting)!
  - Peak load (limited SEA)!
  - Expensive numerical modeling!





Plastic folding of metal tubes

- Possible improvements
  - Stabilizing components
  - Triggers
  - Shape optimization



J. Marzbanrad et al., An energy absorption comparison of square, circular, and elliptic steel and aluminum tubes under impact loading, T. J. Eng. Env. Sci. 33, 2009

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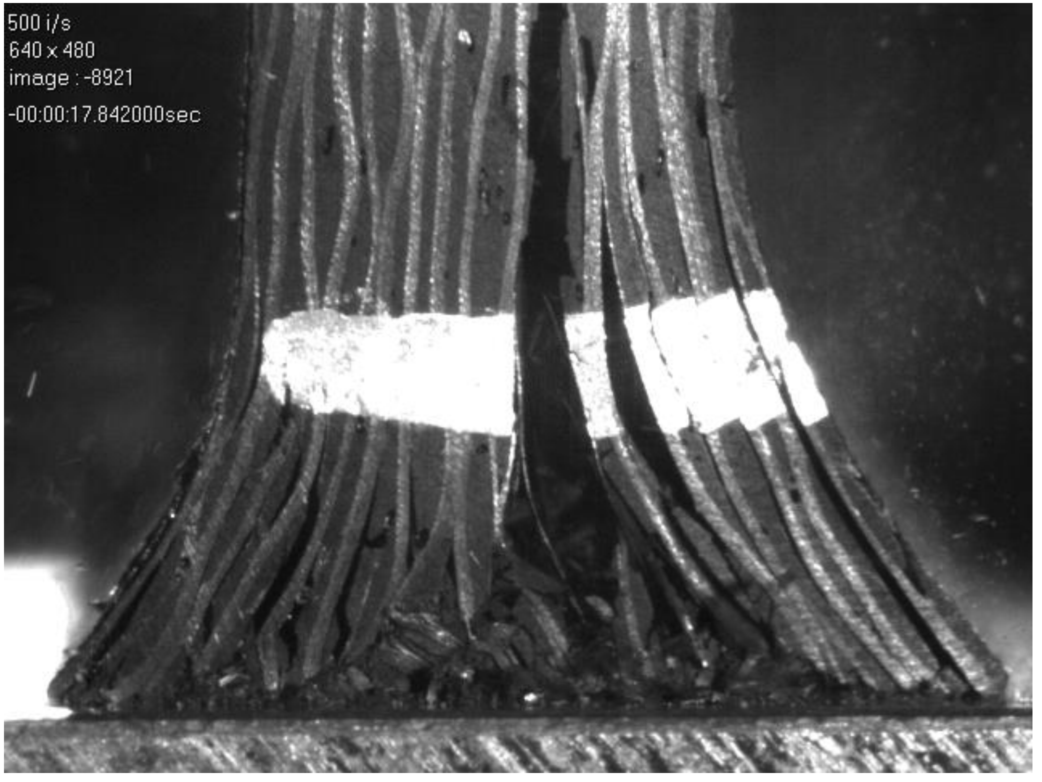
Fragmentation of laminates

- Principle:

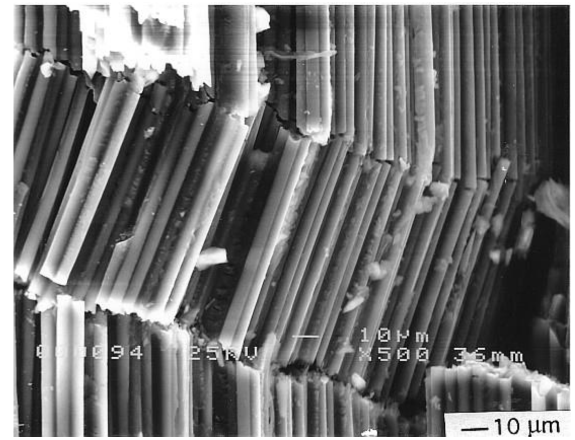


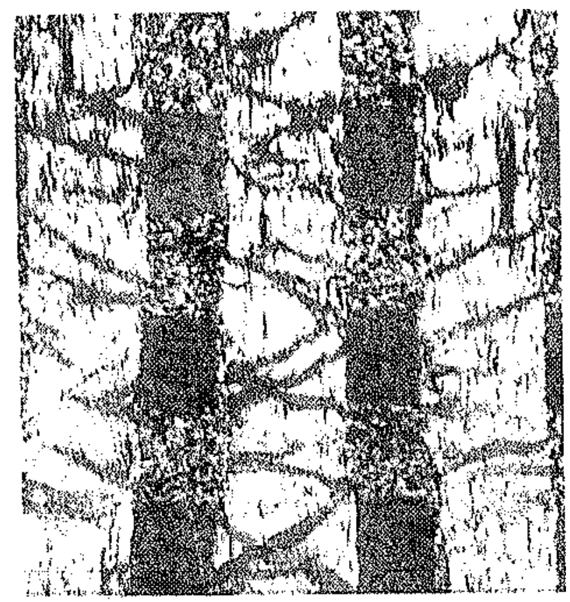
Damien Guillon, *Étude des mécanismes d'absorption d'énergie lors de l'écrasement progressif de structures composites à base de fibre de carbone*, Thèse de doctorat de l'Université Paul Sabatier, 2008

Fragmentation of laminates

- Mechanisms and limits
  - Fibre microbuckling and delamination leading to fragmentation

$$EIw'' + P\left(w + w_0\right) - T\left(w\right) = 0$$





conjugate kink-bands

B. Budiansky, *Micromechanics*, Computers and Structures 16(4), 1983

Fragmentation of laminates

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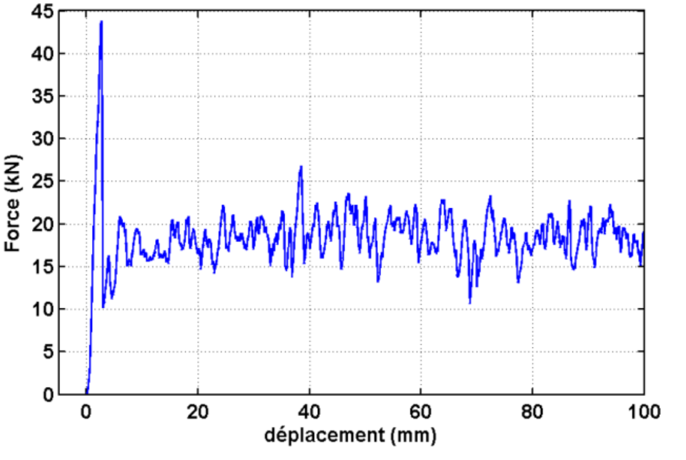
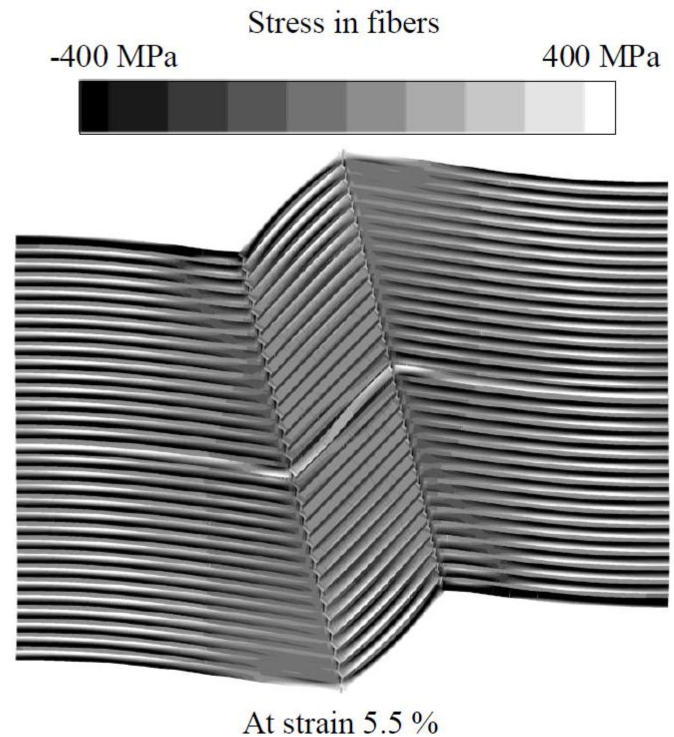


Fragmentation of laminates

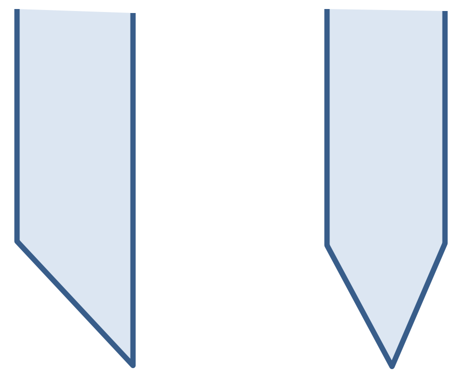
- Mechanisms and limits
  - Fibre microbuckling and delamination leading to fragmentation
  - Global geometric and/or material instability!
  - Peak load (but high SEA)!
  - Impossible FEA modeling!

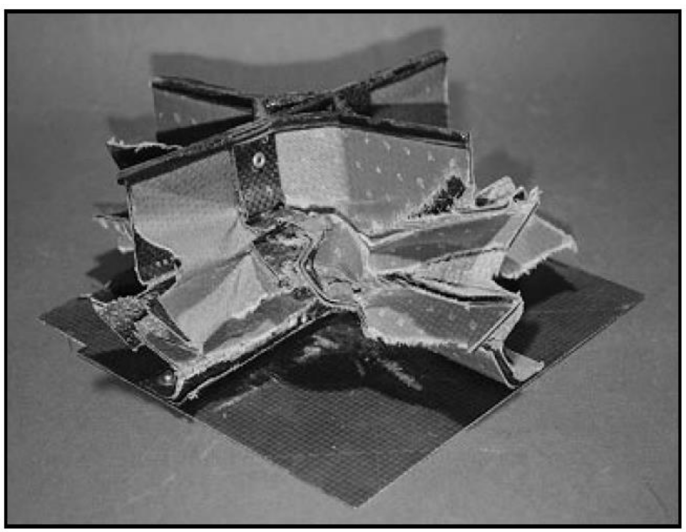


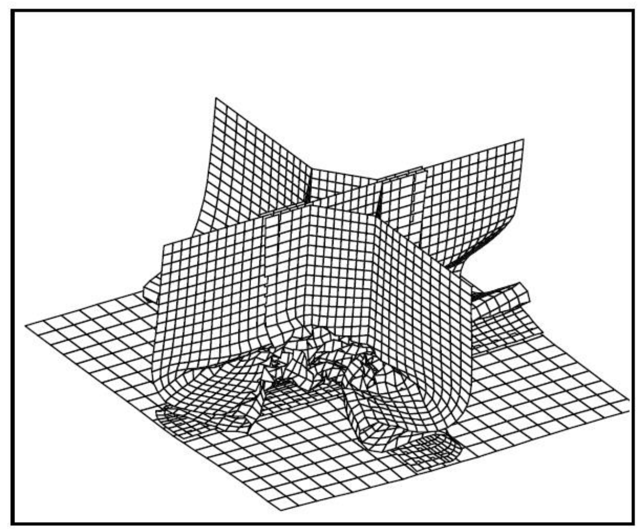
T. Nadabe and N. Takeda, *Numerical Analysis for Effect of Applied Shear Stress on Longitudinal Compressive Strength of Fiber Reinforced Composite Materials*, MCE, 2014

Fragmentation of laminates

- Possible improvements
  - Shape optimization
  - Triggers
  - Upscaling







A. Johnson and A. K. Pickett, *Impact and crash modelling of composite structures: a challenge for damage mechanics*, 1999

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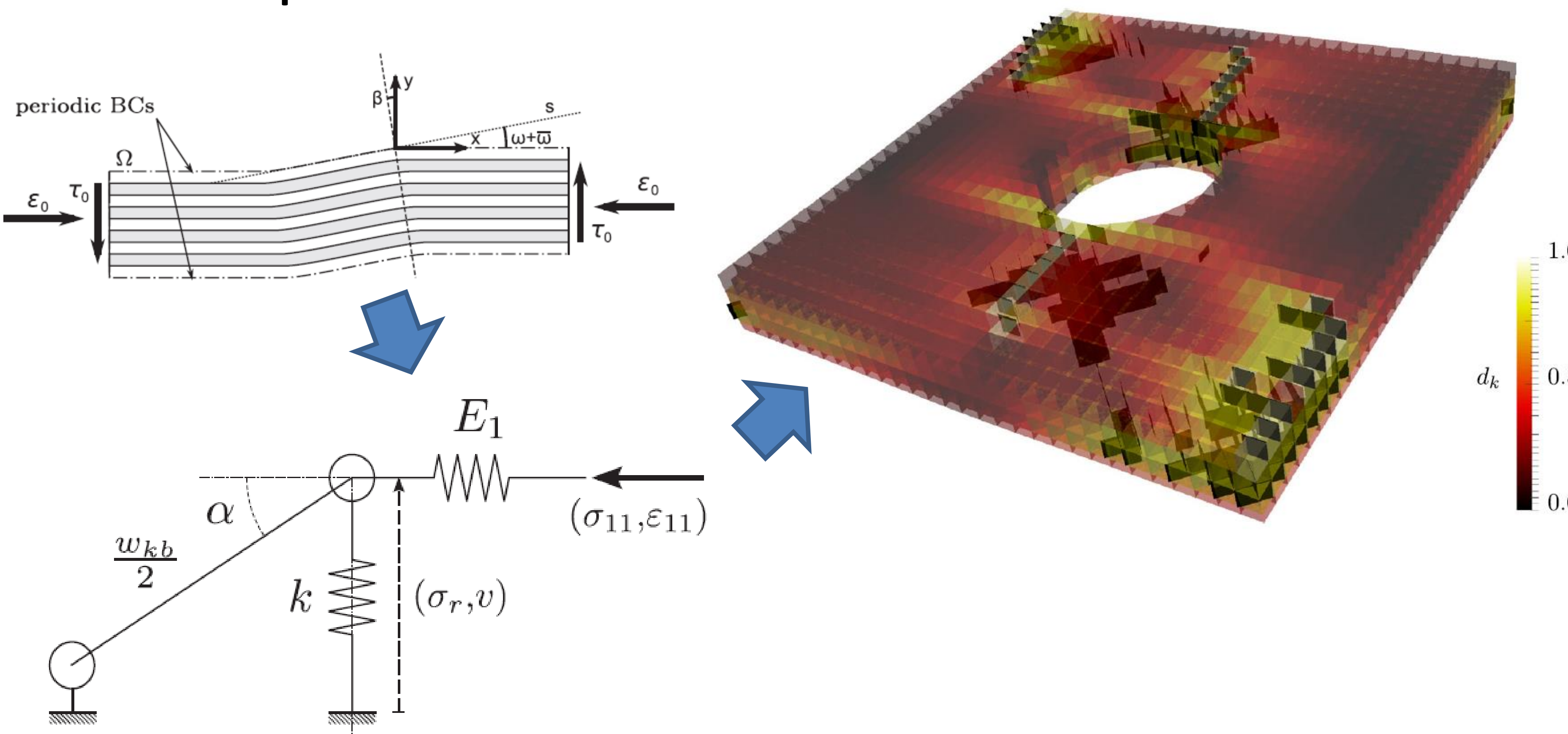
Perspectives

- The question of scales



N. Feld, O. Allix, E. Baranger, J.-M. Guimard, 2011, 2012 & 2014

Perspectives

- The question of scales
- Future solutions: foams, honeycombs, origamis, microlattices… Similar problems? Fundamental mechanisms up to now:
  - Energy storage through plastic buckling/bending
  - Potential energy release through fragmentation
  - … other options?